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METALLIC TITANIUM AND ITS ALLOYS

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BY

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METALLIC TITANIUM AND ITS ALLOYS[1]

By R. S. Dean[2] and B. Sikes[3]

INTRODUCTION

Titanium is estimated to comprise about 0.65 percent of the earth's crust and to be the ninth most abundant element. It ranks fourth in abundance among metallic elements suitable for engineering uses and is exceeded only by aluminum, iron, and magnesium. The titanium industry revolves around the production of ilmenite and rutile. Ilmenite is used to manufacture titanium dioxide, largely employed as a white pigment in paints, but is also utilized in alloys, cemented carbides, and other metallurgical applications. Rutile is used principally for welding-rod coatings, but also for alloys. Supplies of titanium ores previously came largely from the beach sand of Travancore, India, but a large domestic supply has been developed in the Adirondack region of New York, and other deposits are known in Wyoming, Virginia, Arkansas, and other States. There are, also, great quantities of titaniferous magnetite sands in Japan and titanium ore deposits in Russia. In 1939 more than 250,000 tons of titanium concentrates were imported into the United States, principally from the Travancore coast, India. Imports from all sources decreased to 10,407 tons in 1942 and were finally cut off from overseas by the war. Shipments for 1944 from India and Dependencies reached 62,066 tons. Domestic output of ilmenite concentrate for 1944 reached approximately 220,000 tons.

Titanium dioxide is ordinarily produced from ilmenite by digesting with fuming sulfuric acid, filtering, and clarifying the solution of iron and titanium sulfates, reducing the iron to the ferrous state and precipitating TiO_2 by hydrolysis.

Other processes for the production of TiO_2 have been proposed, including some in which titanium tetrachloride is produced as an intermediate product. The process patented by Carteret and Devaux(19)[4] is an example. This process consists essentially of the following steps. The finely pulverized ore is reduced at red heat with coal and then treated

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[1] The Bureau of Mines will wlecome reprinting of this paper provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Information Circular 7381."
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[4] Numbers in parentheses refer to items in the bibliography at the end of this paper.

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with dry chlorine gas. The two operations may be carried out simultaneously by using a reducing gas mixed with the chlorine. The various chlorides (Fe, Si, Ti, etc.) are formed successively as the temperature increases and are subsequently separated by fractional distillation. The aqueous $TiCl_4$ solution is treated with alkali carbonate, ~~and~~ gelatinous TiO_2 is obtained. On boiling in a bath slightly acidified with H_2SO_4, it passes to a dense, unctuous mass, suitable for use as a pigment.

$TiCl_4$ was also produced during the war in considerable quantity for use in smoke screens.

The logical starting points for producing metallic Ti are therefore either the dioxide or the chloride.

PREPARATION OF THE METAL

Before 1900 all attempts to prepare pure titanium were unsuccessful(8,9). In the light of present knowledge, it seems that the early investigators had obtained various mixtures of the carbide and the nitride which they had mistaken for the metal itself, since the carbide and nitride have a metallic appearance and are good conductors of electricity. In 1887 Nilson and Pettersson(34) obtained a product containing about 95 percent titanium by reducing the tetrachloride with sodium. In 1895 Moissan(33) prepared metallic titanium of 98 percent purity by reducing titanium dioxide with carbon in an electric furnace. Hunter(27) heated titanium tetrachloride with an equivalent quantity of sodium in an iron bomb and obtained a product containing 99.7 to 99.9 percent titanium. Similar results were obtained by Lely and Hamburger(49), Podszus(36), and Patterson(35). Billy(17) modified Hunter's process by passing titanium tetrachloride vapors over sodium hydride heated to 400° C. The resulting metal contains hydrogen, which may be removed by heating to 800° C. in a vacuum. Weiss and Kaiser(39) obtained a somewhat impure metal by reduction of the alkali fluotitanates with sodium. Van Arkel(50), using larger quantities and pure K_2TiF_6 or Na_2TiF_6, which was heated with a slight excess of sodium tightly packed in an iron tube, obtained a metal powder which was used for preparing pure titanium according to the iodide process described later.

The Van Arkel method has proved more advantageous than the sodium reduction method, as the pressure does not become too high, although the fluotitanate used must be perfectly dry.

Titanium has also been prepared by passing $TiCl_4$ into a closed vessel containing a fused mixture of NaCl and KCl covered with a layer of molten sodium and maintained at a high temperature. The titanium formed sinks in the melt, which is subsequently extracted with water(21).

The hydride process of Alexander(15) depends on the reduction of titanium dioxide by means of calcium hydride to form titanium hydride and calcium oxide. The reaction is carried out in a hydrogen atmosphere at 400° to 500° C. Calcium oxide may be leached out with cold dilute hydrochloric acid to leave pure titanium hydride, which, after drying at room temperature, is obtained in the form of a fine, steel-gray powder. The disadvantage of this process is that the titanium is always produced first as a hydride, and only by subsequent degassing is it converted into metallic titanium. Even this contains an appreciable amount of hydrogen. For several purposes, this contamination is not desirable. When ductile titanium is desired, titanium produced by other methods must be used. The most favorable conditions reported by Kats and Khokhlova(29) for the reduction of titanium dioxide with calcium hydride in hydrogen at atmospheric pressure are a temperature of 950° to 1,075° C., a 50-percent excess of the 80-to 90-percent CaH_2, and duration of heating 45 minutes to 1 hour.

Many investigators have made experiments on the electrolytic deposition of titanium from a solution, without much success. Several have reported precipitation of small amounts of metallic titanium by electrolysis of aqueous solutions of the sulfate containing sodium sulfate and not too much free acid. A metal having a high overvoltage, such as lead or zinc, is used as the cathode. Electrolysis of solutions of the dioxide is fused alkali fluorides or fluotitanates has been tried. Electrolysis of various mixtures of fused salts has claimed a great deal of experimental effort, with little in the way of positive result. Electrolysis of solutions of anhydrous titanic chloride in various anhydrous organic liquids has also been attempted.

Lubowsky(31) produced titanium in reguline form by effecting a thermit reaction of a mixture of rutile, metallic aluminum, and an alkaline-earth carbonate.

Comstock(105) reported that titanium dioxide can be successfully reduced to titanium by sodium or calcium, but not by aluminum. When aluminum is used, a low-carbon ferrotitanium is produced containing 22 to 42 percent titanium and 3 to 8 percent aluminum.

Comstock and Efimoff(20) prepared powdered metallic titanium by heating titanium tetrachloride with sodium in a closed vessel in the presence of a minor proportion of titanium dioxide or titanium nitride and crushing the resulting product to a powder.

Summarizing, the various methods proposed or used for preparing metallic titanium may be divided into three groups. The first group includes procedures that form the metal by decomposition of a titanium compound by means of a more active element; the second group, methods that depend on decomposition of a solution of a titanium compound by passage of an electric current; and the third group methods that depend on decomposition of a pure titanium compound by direct application of some form of energy.

PREPARATION OF DUCTILE TITANIUM

The success of any process for producing metallic titanium may be judged on the basis of how completely it prevents gaseous contamination

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of the metal. Reduction processes which use metals like aluminum or nonmetals like carbon and silicon yield strongly contaminated metal. Kroll(165), using the Hunter process but a larger bomb, obtained malleable granulated metal. Lely and Hamburger(49) remarked that the grain prepared by them was ductile. In a later work, Kroll(45) reduced titanium dioxide to metal with distilled calcium and calcium chloride-barium chloride mixture (75-25 percent) in an electric furnace in an atmosphere of argon. The reaction is not complete, and the product is mixed with the salt mixture and calcium hydride and reduced again. The metal is workable hot, although cold-short, due to the presence of small quantities of lower oxides.

Two methods of producing metallic titanium pure enough to be ductile at room temperature are available at present. One, developed by Van Arkel, De Boer, and Fast(42,43,44,50,51), involves thermal decomposition of titanium iodide on a heated surface, whereby metallic titanium is deposited on the surface and iodine is liberated as a gas. This technique gives analytically pure titanium, provided pure starting material is used. This method is not easily adaptable to large-scale production, and there is little opportunity to modify the mechanical properties of the metal by alloying with other metals, since the titanium is produced in pencil-shaped rods that cannot be melted into larger lots without contamination.

The other method involves reduction of titanium tetrachloride by a more active metal and yields titanium in a grannular or powdered form more readily adapted to subsequent fabrication. The Hunter process mentioned previously uses sodium, while the Kroll(48) process uses molten magnesium. Kroll reduced titanium tetrachloride with pure magnesium in a molybdenum-lined electrically heated crucible, in the presence of pure argon, at a temperature of about 1,000° C. and separated the metal from magnesium salts by leaching and acid treatment. The resultant powdered metal may be compressed into bars and sintered or melted in a special electrical vacuum apparatus. After melting, the metal can be easily rolled hot to thin sheet.

After considering virtually every process that had been proposed for the production of ductile titanium, Dean and associates(41) concluded that the Kroll process(48) was the most practical for large-scale operations.

They modified the Kroll process in a number of ways. The size of the reduction apparatus was increased stepwise to a potsize capable of producing 100 pounds of titanium per batch. The apparatus used at Salt Lake City for the 15-pound runs is shown diagrammatically in figure 1(41). In this size reduction is carried out in an unlined iron pot. The pot, 12 inches in diameter and 14 inches in height, was made from 12-inch pipe with 3/8-inch plates welded on the ends. The inside surfaces of the pot were carefully cleaned by pickling in dilute HCl, scraping, and finally polishing with an emery cloth. The cover was then welded on and the assembly heated to 500° C. while filled with hydrogen to reduce the oxide formed on the interior surfaces by the welding. After cooling, 20 pounds of carefully cleaned magnesium ingots were introduced through the inlet

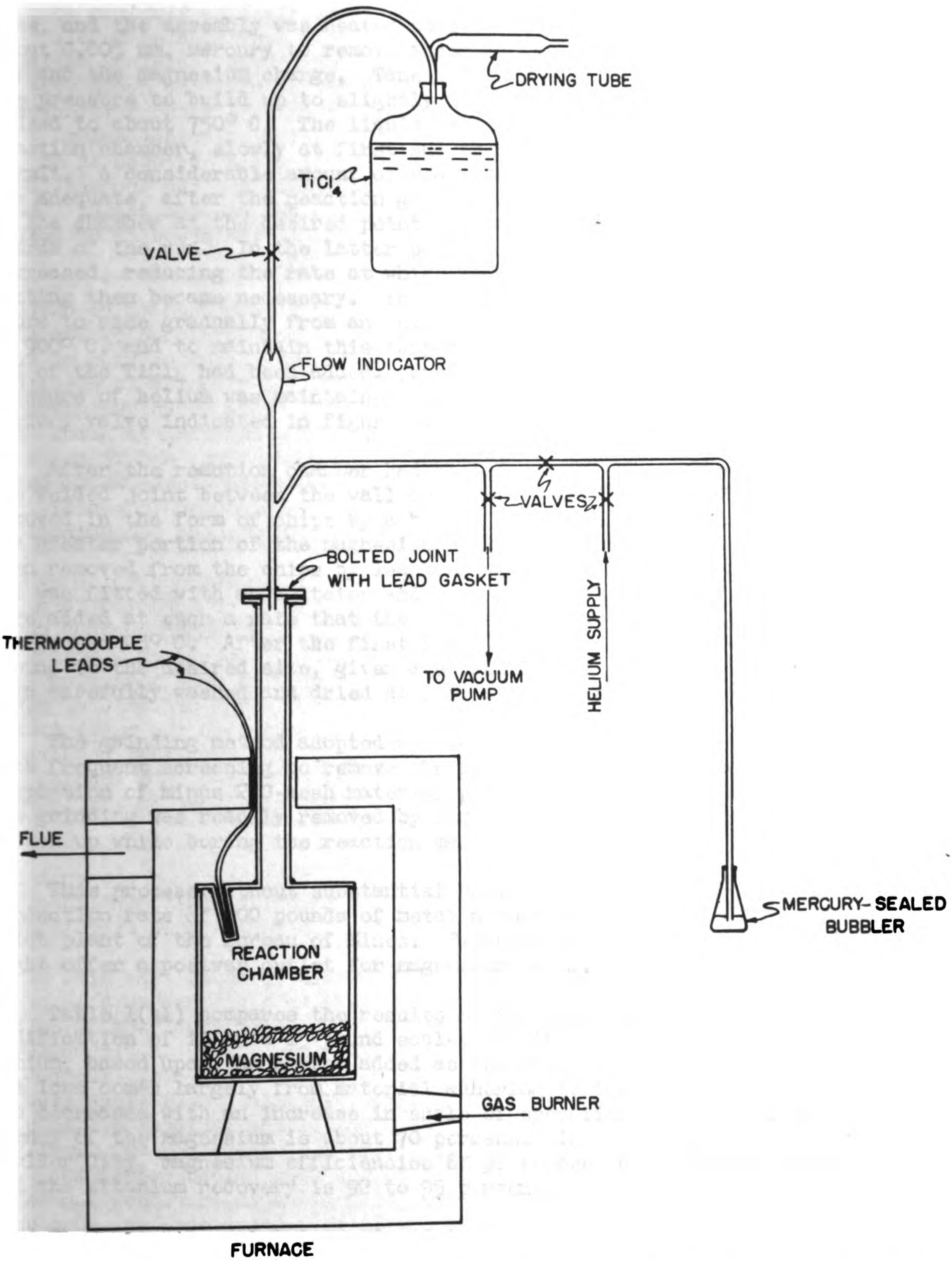

Figure 1. - Diagrammatic sketch of apparatus used at Salt Lake City, Utah, for 15-pound runs.

tube, and the assembly was heated to 150° C., evacuating to a pressure of about 0.005 mm. mercury to remove absorbed gas from the walls of the chamber and the magnesium charge. Tank helium was next introduced, allowing the pressure to build up to slightly above atmospheric, and the temperature raised to about 750° C. The liquid titanium tetrachloride was run into the reaction chamber, slowly at first and then as rapidly as the reaction would permit. A considerable amount of heat was evolved. This evolution of heat was adequate, after the reaction got under way, to maintain the temperature of the chamber at the desired point without external heating for about two-thirds of the run. In the latter portion of the run, the rate of reaction decreased, reducing the rate at which $TiCl_4$ could be added, and external heating then became necessary. The normal practice was to allow the temperature to rise gradually from an initial value of 750° C. to a final value of 900° C. and to maintain this temperature for about one-half hour after all of the $TiCl_4$ had been added. During the entire run, a slight positive pressure of helium was maintained in the reaction chamber by means of the mercury valve indicated in figure 1.

After the reaction chamber had cooled, it was opened by cutting through the welded joint between the wall and the top of the pot. The charge was removed in the form of chips by a boring operation carried out on a lathe. The greater portion of the magnesium chloride and excess magnesium were then removed from the chips by leaching with cold HCl. The leaching vessel was fitted with an agitator and cooling device, and the reaction chips were added at such a rate that the temperature of the leaching liquor did not exceed 25° C. After the first leaching, the chips were washed, dried, ground to the desired size, given a second leaching in 10 percent HCl, and then carefully washed and dried at room temperature.

The grinding method adopted was wet grinding in a small ball mill, with frequent screening to remove the undersize particles and reduce the proportion of minus 200-mesh material produced. The iron introduced by the grinding was readily removed by magnetic separation along with that picked up while boring the reaction mass out of the chamber.

This process without substantial modification has been used for a production rate of 100 pounds of metal a week at the Boulder City, Nev., pilot plant of the Bureau of Mines. Titanium production by this process might offer a postwar outlet for magnesium metal.

Table 1(41) compares the results of the Kroll process and the Bureau's modification of it on a 15-pound scale. In the latter the yield of titanium, based upon the amount added as chloride, is about 85 percent. The loss comes largely from material adhering to the walls of the chamber and decreases with an increase in scale of operation. The reducing efficiency of the magnesium is about 70 percent. In the larger operations at Boulder City, magnesium efficiencies of 90 percent are commonly obtained, and the titanium recovery is 92 to 95 percent.

The grannular metal is produced in a high state of purity, containing about 25 cc. of hydrogen per gram of metal and 0.50 percent magnesium, both of which are completely removed by sintering at 1,000° C. in high vacuum. The powder may contain up to 0.1 percent iron and a few tenths percent of

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oxygen as the oxide. The silicon content is believed to be less than 0.1 percent. These latter impurities are not present in sufficient amounts to interfere with the ductility of the metal.

TABLE 1. - Data on reduction process

			Bureau of Mines		Kroll
Reduction-pot size .... in.	1-1/2	3-1/2	6	12	-
Temperature ranges .... °C.	750-1,000	760-850	740-820	800-870	740-1,0
Magnesium used .... gm.	21	200	1500	1/21.5	360
$TiCl_4$ added .... do.	63.8	638	4730	1/62.5	1138
Time of $TiCl_4$ addition........ min.	66	145	140	205	110
Titanium powder produced ...... gm.	11.8	144	1067	1/14.5	284
Ratio $TiCl_4$:Ti	0.19	0.22	0.22	0.23	0.25
Percent of theoretical yield	73	89	89	92	98
Ratio Ti:Mg	0.56	0.72	0.71	0.68	0.79
Reduction efficiency of Mg. percent	57	73	72	69	80

1/ Pound.

POWDER METALLURGY, FABRICATION, AND PROPERTIES OF DUCTILE TITANIUM

The granular metal produced by Dean and associates(41) was satisfactorily consolidated by pressing into compacts at a pressure of 50 tons per square inch and sintering for 16 hours at 950° to 1,000° C. in a vacuum of $1x10^{-4}$ mm. mercury. At this pressure, the compression ratio of the powder is about 3.5: 1. The sintered compacts are ductile, lend themselves readily to cold deformation, and have been made into sheet and bar by specific fabricating methods. It should be pointed out that the data on the physical properties reported in that paper were obtained on metal fabricated by a fixed procedure, standardized for the purpose of control of the reduction, and are representative only of material fabricated under those conditions. Average physical properties, as well as some additional data on the melting point, transition temperature, and X-ray parameters as reported by Fast, are given in table 2(41). These are excellent physical properties and place titanium high in the list of strong, light metals. Annealed material has a tensile strength of about 82,000 pounds per square inch, with 28 percent elongation and a hardness of 55 on the Rockwell A scale. It is hardened by cold working; tensile strength for 50-percent reduction by cold work is about 126,000 pounds per square inch with 4-percent elongation and a Rockwell hardness of A 65.

In another paper, Dean and associates(54) determined the physical properties of titanium metal on 1/16-inch sheet, using standardized procedures for pressing compacts, sintering, forging, and annealing. The compacts, after pressing at 50 tons per square inch, were sintered for 16 hours at 1,000° C. in a vacuum of 2×10^{-4} mm. of mercury. The sintered compacts have a density of 4.30, a tensile strength of 83,000 pounds per square inch, an elongation of 10 percent, and a Rockwell hardness G 54. They are best worked by cold forging and may be reduced as much as 50 percent in thickness in this operation. Compacts were normally forged to 25-percent reduction and

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in this condition have a density of 4.42, a tensile strength of 115,000 pounds per square inch, 6-percent elongation, and a hardness of G 81. Physical properties, hardness, and microstructure were followed at all stages of the working and also on sheet annealed at temperatures ranging from 400° to 1,200° C. Vacuum annealing for 6 hours at 1,000° C. gives a slight increase in density and reduces the strength and hardness to about those of the sintered compact. The forged and annealed compacts were cold-rolled by slight reductions and many passes, with intermediate annealing after 15- to 20-percent reduction, and finished into sheet with 10- to 60-percent reduction.

TABLE 2. - Properties of metallic titanium

	Cold-worked	Annealed
Tensile strength .... lb./sq. in.	126,000	82,000
Yield strength .... do.	100,000	62,000
Proportional limit .... do.	72,000	55,000
Elongation .... percent in 2 inches	4	28
Young's modulus .... lb./sq. in. x 10^6	15.4	16.8
Hardness .... Rockwell A	65	55
Melting point .... °C.	1,725	
Electrical resistivity .... ohms per cm.^{3}x10^6	56	
Density .... gm./cc.	4.5	
Crystal structure up to 880° ± 20° C., hexagonal close-packed	a=2.95	c=4.73
Above 880° C., body-centered cubic	a=3.32	

Tensile strength is increased by cold-rolling from 78,700 to 123,000 pounds per square inch by 50-percent reduction and then drops to 111,500 pounds per square inch at 60-percent reduction, indicating overwork. The percentage of elongation decreases from 25.2 to 8.2 at 20-percent reduction and drops to 1.5 at 60-percent reduction. The hardness rises regularly with working from G 6 for annealed material to G 92 for 60 percent coldwork.

Rolling at 500° C. permits greater reductions per pass and larger total reductions between anneals. The temperature is below the recrystallization temperature of titanium, and material so rolled work-hardens to a much smaller extent than in cold-rolling. Reductions of 80 percent raise the tensile strength to 101,700 pounds per square inch and the hardness to C 88, while the elongation drops irregularly to 10 percent in 2 inches.

Annealing after cold-and hot-rolling produces similar properties for a given annealing temperature. Minimum strength is reached on annealing between 700° and 900° C. Cold-rolled, annealed metal has a slightly higher tensile strength - 79,000 pounds per square inch compared to 73,000 pounds per square inch - and a hardness of G 79 versus G 75, while the elongation of 25.2 is slightly lower. Annealing temperatures of 1,000° to 1,200° C. produce a small increase in the tensile strength and a decrease in elongation.

Some of the metal produced was swaged into rods and then drawn into wire 0.006 inch in diameter. The small rod and wire could be annealed for further drawing by heating for 20 minutes to 1 hour at 600° C. in air without excessive oxidation.

The metal has excellent corrosion resistance, being very similar to 18-8 stainless steels in this respect. It is, however, rapidly attacked by concentrated H_2SO_4 and HCl, and dilute H_2SO_4 attacks the metal slowly, but concentrated and dilute HNO_3 have no appreciable effect. The metal does not tarnish on exposure to laboratory atmospheres or during a 30-day exposure to the salt-spray tests. Physical properties are also unaffected by salt-spray corrosion tests. The consolidated material is quite stable.

The mean specific heat of titanium has been measured by several investigators; only Jaeger and associates(61) used ductile titanium. The measurements by Jaeger and his collaborators seem to be in error, due to gas absorption. In the following table from Van Arkel(12), several values of the mean specific heat are compiled.

Nilson and Pettersson(34)		Hunter and Jones(28)		Jaeger and others(61)	
Cp	Temp. range, °C.	Cp	Temp. range, °C.	Cp	Temp. range, °C.
0.1125	0-100	0.1462	0-100	0.1291	0-219
.1288	0-211	.1503	0-187	.1316	0-266
.1485	0-301	.1516	0-254	.1334	0-320
.1620	0-440	.1563	0-333	.1386	0-500

According to DeHaas and Van Alphen(55), titanium becomes superconducting below 1.63° K.

Concerning the optical properties of titanium, Went(12) determined for the line 6650A. the emission coefficient as a function of the temperature. His results are given as follows:

Temp. .... °K.	1150	1250	1350	1450	1550	1650
Emission coefficient	0.533	0.523	0.502	0.480	0.450	0.419

Bridgman(53) measured the linear compressibility of titanium obtained by the electrolysis of fused salts. He calculated the following results for volume compressibility from his linear measurements by assuming equal compressibility in all directions:

$$\text{At } 30^\circ - \Delta V/\Delta V_o = 7.97 \times 10^{-7} p + 0.12 \times 10^{-12} p^2.$$
$$\text{At } 75^\circ - \Delta V/\Delta V_o = 8.68 \times 10^{-7} p - 4.5 \times 10^{-12} p^2.$$

Bridgman notes that (a) compressibility increases greatly with temperature, (b) the direction of curvature at 30° is abnormal, and (c) the value 7.97×10^{-7} fits in well with the position of Ti in the periodic table.

Kroll(166) reported that the Brinell hardness of titanium prepared from titanium tetrachloride and sodium is about 210 and is raised by alloying additions. Oxygen increases it to about 320, when red-shortness occurs. Cold-drawing gives 260 Brinell.

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DeBoer(12) found that two titanium samples prepared by the iodide process had a Vickers hardness of 188 and 122 Kg. per mm.^{2} when tested with a load of 5 Kg.

Hidnert(60) found that the coefficient of expansion of titanium increases from about 5×10^{-6} per degree at -150° C. to about 12×10^{-6} per degree at 650° C.

The surface of ductile titanium can be hardened by heating in a controlled atmosphere containing small amounts of oxygen or nitrogen. Considerable experimental work of the Bureau of Mines, carried on by vacuum methods and by the use of purified helium atmospheres, has shown that 1.3 mg. of oxygen per square centimeter of titanium surface will produce a layer with a hardness of Rockwell C 58 at 0.04 millimeter below the surface. The thickness and hardness of this layer, which appears to consist of a solution of TiO in Ti, may be modified by regulating the temperature of formation and time allowed for diffusion to take place. Optimum conditions appear to be reached at 950° C. and within 24 hours.

USES OF DUCTILE METALLIC TITANIUM

Until the recent work by the Bureau of Mines, titanium had been available only in very small quantities. Its commercial uses, therefore, have not been developed to any great extent.

It has been employed in the form of rods to produce spectra for astronomical research, and filaments of titanium have been used in incandescent bulbs. Many important uses of titanium have been suggested which can now be tried out. These suggested uses, for the most part, revolve around the fact that titanium is a light, corrosion-resistant metal, thus combining the properties of stainless steel with those of the strong aluminum alloys.

Ductile titanium possesses certain definite advantages over both stainless steel and the aluminum alloys. One such outstanding advantage is its high proportional limit. The proportional limit of cold-worked titanium is as high as 75,000 pounds per square inch. This is to be compared with the unusually low proportional limit of stainless steel, which is not more than 25,000 pounds per square inch, even when fully cold-worked. The aluminum alloys do not have a true proportional limit. The proportional limit of titanium is comparable with heat-treated steels and aluminum bronze, and since its density is only a little over half that of steel or aluminum bronze, it is seen that wrought titanium is in a class by itself, so far as the weight of a section having a given proportional limit is concerned. It is obvious, therefore, that where a minimum weight combined with a continued high stress is concerned, titanium would be the preferred structural material. There are a great many places in aircraft design where such a situation prevails. Eventually, titanium will be produced at a cost where it can be freely used for structural purposes. At the outset, while it is still a relatively expensive metal, it should find uses in all sorts of diaphragms that are maintained under tension, particularly such elements as microphone diaphragms where weight is important. It should also find early use in textile machinery, where a considerable saving in power can be made by using a light metal for high-speed spindles, spools, warp beams, and other working parts. Magnesium alloys have been suggested for these parts, but the very much greater stress to which titanium can be used overcomes, to a considerable extent at least, the lower weight of magnesium.

The fact that titanium can be surface-hardened also gives it a definite advantage over the light metals in the construction of parts subject to frictional wear. The use of titanium for automotive pistons has also been suggested. In this field, it possesses not only a combination of lightness and strength but also a coefficient of expansion which is actually a little less than that of cast iron, ordinarily used for cylinders. The heat conductivity of titanium is a disadvantage for the purpose of piston heads, but for a number of other purposes it is a definite advantage. When titanium eventually becomes plentiful and reasonably cheap, it will make excellent pot handles for aluminum pans.

The excellent working and physical properties of titanium suggest it for many sport uses, such as tennis rackets and fishing rods. The modulus of titanium, combined with its especially high proportional limit, should improve the elastic behavior of such equipment.

The combination of stainlessness, high proportional limit, and low modulus makes titanium an ideal material for springs where a considerable extension in relatively low loads is desired. The use of titanium should make possible the construction of greatly improved spring balances.

Titanium, along with zirconium, has the very unusual property of marking glass. This property has been utilized for a variety of purposes, including the production of very stable, high electrical resistances, which are simply made by marking a glass surface with a titanium point.

The low modulus of titanium combined with its strength have also suggested its use in tool mounting where a certain amount of give is desirable to prevent breakage.

The corrosion resistance of titanium, as well as its ability to surface harden, has been utilized in the making of pen points and styluses.

X-ray diffraction tubes with titanium targets are in the developmental stage.

In conclusion, the really large-scale use of ductile, metallic titanium would appear to depend only on its availability in suitable form and at a price where it will no longer be considered a rare and precious metal.

ALLOYS OF TITANIUM

While considerable information is available on the addition of titanium to various metals and alloys, relatively little is known concerning

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the effects of adding other metals to titanium. This field will undoubtedly prove to be quite fruitful. Hansen(142) in his textbook on binary alloys gives information about the following titanium alloys:

Al, B, Fe, Au, Co, C, Cu, Ni, P, Pt, Hg, S, Se, Si, N, Te, H, Zr.

Ferro-Alloys Containing Titanium

Alloys of titanium, such as ferrotitanium, ferrocarbontitanium, cuprotitanium, and manganotitanium, are added to molten metal as scavengers just before casting. This use depends upon the high chemical reactivity of metallic titanium. It removes oxygen and nitrogen from the bath more completely than either silicon or manganese. It is not so strong a deoxidizer as aluminum but for many purposes is more satisfactory than aluminum, since its use does not cause intergranular occlusions of sulfide to the extent that the use of aluminum does.

Ferrocarbontitanium is the ferro-alloy most used as a deoxidizer in steel and gray cast iron. In amounts up to a few pounds per ton, it is added just before casting. It is made by the Rossi process, in which ilmenite and coke are smelted in contact with a bath of steel in a special type of electric furnace. High-carbon ferrocarbontitanium contains 15 to 18 percent titanium and 7 to 8 percent carbon and is used for adding titanium to medium- and high-carbon steels and cast irons. Medium-carbon ferrocarbontitanium contains 18 to 21 percent titanium and 3.5 to 4.5 percent carbon. It is used for low-carbon steels. High-aluminum ferrocarbontitanium contains 12 to 16 percent titanium, 18 to 22 percent aluminum, 2 to 4 percent silicon, and 3 to 5 percent carbon. It is used for making fine-grained steels by simultaneous additions of titanium and aluminum.

It has been found that titanium-carbon ratios between 3.5 and 5.5 in 5-percent chromium steel containing molybdenum and titanium give better notch toughness and high-temperature rupture strength than with higher titanium, together with satisfactory ductility and restriction of air hardening. Silicon around 1 percent is beneficial to oxidation resistance of this steel(107).

Comstock(99) has found that the use of titanium with boron is advantageous in promoting hardenability and toughness of the hardened steel.

Another use for titanium in ferrous metallurgy depends on the reaction of free metallic titanium with carbon or metallic carbides to form titanium carbide, after the oxygen has been removed. Titanium carbide is immiscible in the solid state and separates as separate random crystals having little effect on the properties of the metal. Therefore, titanium may be used as a method of carbon control in such alloys as high-chromium steel, in which intergranular carbide formation is objectionable. It has been claimed that hardening of a steel by precipitation of iron carbide would be impossible if an excess of free metallic titanium were present.

Slag inclusions in titanium-treated steel are more fusible and fluid because of the presence of titanium dioxide and are therefore readily eliminated by floating out of the freezing steel, giving cleaner metal.

A large amount of titanium is used in effervescing steel, for many plants have found it to give better rimming ingots and hence a higher yield of good product. Its use in rimming steel is not entirely because of deoxidation, but partly because of the fluxing action of the titanium dioxide formed.

Titanium is also used in cast steel, especially pearlitic manganese steel, where a stronger deoxidizer than silicon is needed. The use of titanium for this purpose gives inclusions that are globular and scattered. Titanium is used in steel castings to give the proper degree of deoxidation for fine-grain characteristics without so much deoxidation as to incur trouble from inclusions.

For carbon control purposes, ferrotitanium is used, since ferrocarbontitanium is not a suitable source of free titanium for this purpose. There are several commercial processes for producing ferrotitanium. One is a modification of the thermite process. The thermite process can be used to reduce a mixture of 1 part titanium dioxide with several parts ferric oxide to give ferrotitanium, which may contain 22 to 42 percent titanium and 3 to 8 percent aluminum, with very little carbon. Another method accomplishes this reduction by dropping the oxides to be reduced onto a bath of molten aluminum. Still another method depends on the fact that at the high temperature of the electric furnace, and in the presence of molten iron, an excess of silicon will reduce titanium dioxide to metal, while at lower temperatures titanium will decompose silica. This last-mentioned process yields a low-carbon aluminum-free alloy for use in gray cast iron.

An alloy containing about 13 percent titanium, 20 percent aluminum, 3 percent silicon, 4 percent carbon, and the balance principally iron has been suggested for carbon steels to deoxidize and produce fine grain. Another group of related titanium alloys comprises ferrotitanium of about 18 percent titanium, 18 percent silicon, 0.5 percent carbon, and 0.5 percent aluminum, with the remainder principally iron. Another similar alloy contains 16 percent titanium, 10 percent silicon, 2.5 percent carbon, and 0.5 percent aluminum. Still another contains 15 percent titanium, 20 percent aluminum, 3 percent silicon, and 4 percent carbon. Also, there are the iron-silicon-titanium alloys, containing 35 percent silicon, 0.3 percent carbon, 0.3 percent aluminum, 30 to 55 percent titanium, and the rest principally iron. Four of these last five alloys have been restricted in their commercial use to the addition of titanium to cast iron.

Titanium in the Metallurgy of Cast Iron

Low-carbon titanium alloys are used for adding titanium to cupola-melted cast iron, to nickel, copper, aluminum, or as an alloying element

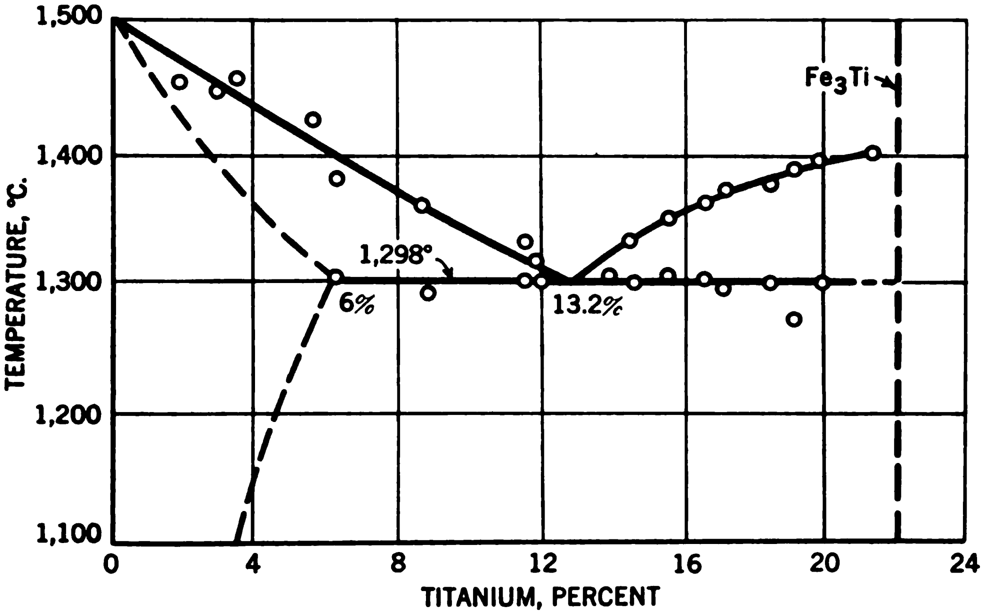

Figure 2. - Iron-titanium constitution diagram, according to Lamort, with solubility line added as suggested by Seljesater and Rogers.

in steel. The effect of titanium addition in cast iron is chiefly to reduce the size of the graphite flakes. Owing to the closer grain of titanium cast iron, the strength is improved 5 to 25 percent, the Brinell hardness is increased slightly, and the mechinability is improved. It also acts as a graphitizer in cast iron, reducing the hardening effect of chill at thin sections and corners. Titanium is thus a useful addition to chromium cast iron or vanadium cast iron, where it allows full utilization of the strengthening effects of these elements. The graphitizing effect of titanium accounts for the improvement it effects in the machinability of these cast irons, while its grain-refining effect maintains or increases their high strength. Comstock and Starkweather(114) have found that the soundness of sand-cast test bars of gray cast iron is improved when the iron is titanium-treated.

Titanium in Special Alloys

Kroll(166) examined a large number of alloys of titanium for their capacity for being rolled and their structure. The hot-rolling property of titanium is improved by additions of small quantities of the metals nickel, iron, cobalt, and tantalum. Solid solutions are probable for the alloys with molybdenum, tungsten, and tantalum.

Titanium-Iron Alloys

The iron-titanium constitution diagram, as reproduced by Comstock(109), is shown in figure 2. This diagram has not been altered materially from the form proposed in 1914 by Lamort(175), who, it is believed, did not use pure materials in his investigation. A solid solubility line has been added according to the results reported by Seljesater and Rogers in 1932 (214). It can be noted from the slope of the solubility line that the possibility of age-hardening is evident. Thus, titanium as an alloying element in steel can be used for hardening and strengthening the austenitic, highly alloyed steels that are not hardenable by heat treatment in the usual manner.

Wasmuht(248) investigated the ability of titanium to produce "precipitation-hardening" and the influence of addition elements on precipitation-hardening in iron-titanium alloys. He showed that precipitation-hardening is produced at titanium contents of over 3 percent in these alloys, while at lower titanium contents the addition of silicon or nickel is necessary for promoting precipitation-hardening, the effect of silicon being two to three times as strong as that of nickel. With decreasing cooling velocity (on cooling from high temperatures with subsequent annealing) of these alloys, the hardening ability decreases. Their critical cooling velocity is decreased by increasing either the titanium content or that of the elements promoting precipitation-hardening.

A new 18-8 stainless steel containing titanium (about 0.9 percent) as the principal precipitation hardening element has recently been reported.

Morral and Bray(187) found that iron alloys containing 25 percent titanium have one-tenth the rate of corrosion of iron.

Titanium-Copper Alloys

Figure 3, reproduced by Hansen(142), shows the copper-titanium constitution diagram, which resembles in a general way the iron-titanium diagram. The eutectic temperature is 878° C., and the eutectic concentration lies between 20 and 27 percent titanium. Titanium forms an age-hardening alloy when added to copper. The reason for the age-hardenability is evident from the slope of the alpha solid-solution curve on the equilibrium diagram. Hensel and Larsen's data(144) on the electrical conductivity of forged samples are reproduced in table 3. The quenching produces a supersaturated solution and gives the highest resistivity values, while as a result of aging a precipitation of the substances held in solid solution occurs whereby the resistivity is greatly reduced.

TABLE 3. - Electrical conductivity of forged samples

Ti, percent	Quenched from 900° C. Resistivity, microhms per cc.	Quenched from 900° C. Conductivity, percent (Cu = 100 percent)	Aged 16 Hr. at 400° C. Resistivity, microhms per cc.	Aged 16 Hr. at 400° C. Conductivity, percent (Cu = 100 percent)
0.83	10.12	17.37	8.255	21.5
2.74	23.6	7.48	9.077	19.6
4.74	40.94	4.53	9.062	19.66

Typical tensile properties, as determined by Hensel and Larsen(144) on forged and heat-treated samples, are shown in table 4.

TABLE 4. - Typical tensile properties

Ti, percent	Treatment	Proportional limit, lb. per sq. in.	Yield point, lb. per sq. in.	Tensile strength, lb. per sq. in.	Elongation, percent in 2 in.	Reduction, percent	Brinell hardness
2.58 ..	a	10,000	21,200	54,000	37.7	46	
	b	26,000	82,000	104,100	16.7	36	
1.5 ...	a	3,500	12,500	41,600	48.5	60.3	63
	b	40,000	52,700	80,500	31.5	49.5	148
	c	34,500	52,400	80,150	31.5	50.0	146
2.90 ..	a	5,600	23,300	56,500	42	44	93
	b	49,000	75,000	104,300	20.0	29.0	200
	c	51,000	77,000	104,500	21.5	29.5	201

a/ As quenched from 900° C.
b/ Quenched from 900° C. and aged for 8 hr. at 450° C.
c/ Quenched from 900° C. and aged for 16 hr. at 400° C.

The age-hardening effects produced by adding small amounts of titanium to copper produce a large increase in the tensile properties. The proportional limit and the yield point are raised, in some cases, as high as 1,000 percent, while the hardness is increased only 100 percent. The increase in tensile strength is directly proportional to the increase in

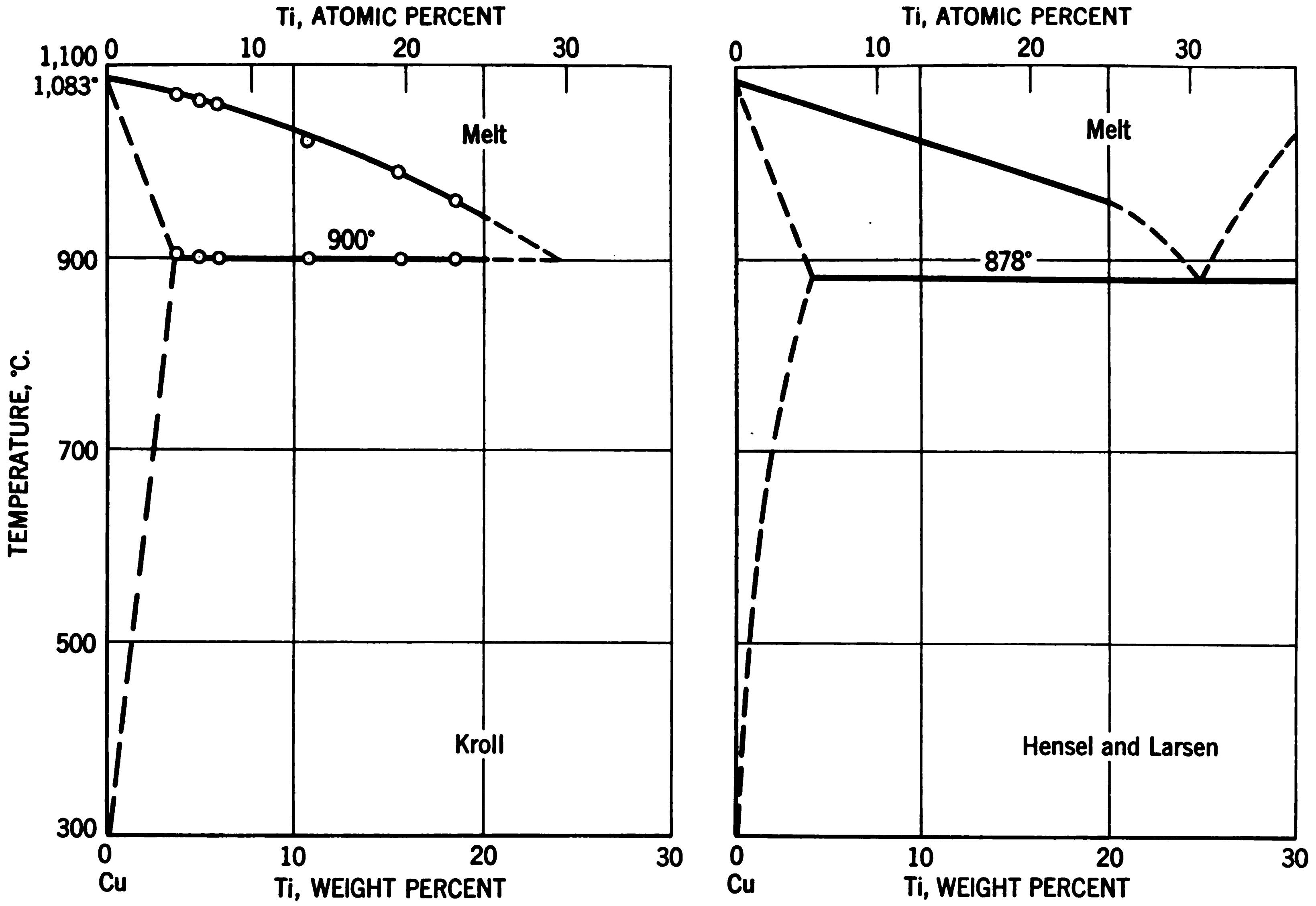

Figure 3. - Copper-titanium constitution diagram.

hardness and the decrease in elongation, but the elongation values are high enough to make the alloy very desirable for structural purposes.

Alexander(68) reported a method of producing Cu-Ti eutectic alloys which utilizes the advantages of powder metallurgy to produce a fused alloy. Powdered titanium hydride and powdered copper are thoroughly mixed in the proportion of the eutectic composition, that is, titanium 28 percent and copper 72 percent. These are mixed in the ball mill until the distribution of titanium hydride particles is perfectly uniform throughout the mass of powdered copper. The powdered mixture is then poured into a crucible and placed in a vacuum furnace. As the temperature reaches 878° C., the melting point of Cu-Ti eutectic, at the point of contact of copper and titanium particles there is the formation of liquid low-melting-point alloy.

It is understood that a copper, chromium, titanium alloy whose approximate composition is 97 percent copper, 1 percent chromium, and 2 percent titanium is used in substantial quantities for making glass to glass and glass to metal seals.

Titanium has been added to beryllium-copper where its function seems to be stabilization of the hardness at higher temperatures than could be endured, without softening by the plain beryllium-copper alloy. This might offer a considerable advantage in such parts as welder contacts, where conductivity is essential as well as hardness on heating or in springs that must maintain their original properties at temperatures above 600° F.

Investigators have shown that the addition of titanium imparts to copper additional tensile strength, which is retained at high temperatures to a greater degree than that of several other copper alloys. This indicates that copper-titanium alloys might find considerable use in such applications as condenser tubes, boilers, etc.

Titanium-Nickel Alloys

Austin and Halliwell(76) showed that nickel and its alloys are hardened by titanium. Thus, titanium has been used to produce a hardenable Invar. The Mond Nickel Co.(186) has patented an alloy, having a low coefficient of thermal expansion, which consists of 34.4 to 60 percent nickel, 1 to 5 percent titanium, 0 to 0.2 percent carbon, and the rest substantially all iron. It has also patented(184) an age-hardenable alloy containing 38.5 to 47 percent nickel, 1 to 4 percent titanium, 2 to 9 percent of a chromium-like element (of which at least 2 percent is chromium), 0 to 0.2 percent carbon, and the rest substantially all iron. Talbot(231) patented an alloy suitable for age-hardening containing 39.3 to 44.3 percent nickel, 2 to 3.5 percent titanium, and 0.001 to 0.07 percent carbon, together with iron, and having a minimum coefficient of expansion and inflection temperatures above approximately 250° F., with high hardness exceeding about 225 Brinell.

Titanium is a constituent of konel, an alloy of ferrotitanium, nickel, and cobalt, said to have good mechanical strength at high temperatures, when most other alloys suffer a great falling off in strength, and thus capable of being employed with advantage in the moving parts of internal-combustion engines and similar duties where resistance to heat is required. This alloy was originally developed as a substitute for platinum in the manufacture of filaments for radio valves, Konel giving 10 times the life of other filaments, while valves fitted with Konel filaments are operated at a temperature some 175° colder than valves with platinum filaments, thus giving better reception results. Woldman and Metzler(251) give the formula for Konel as 73.07 percent nickel, 17.16 percent cobalt, 8.8 percent titanium, 0.55 percent silicon, 0.16 percent manganese, and 0.26 percent aluminum. They give the following data for mechanical properties: Tensile strength, 100,000 lb. per sq. in.; yield point, 40,000; elongation, 35 percent; reduction of area, 55 percent; and Brinell hardness, 140. A typical Konel alloy patented by the Westinghouse Electric & Manufacturing Co.(249) has the composition 73 percent nickel, 18 percent cobalt, 7 percent iron, and 2 percent titanium.

The chief use of titanium in nickel is as a deoxidizer or degasifier in welding. It has been found that titanium is almost indispensable for making sound nickel welds. Titanium is widely used in the form of an alloy powder in nickel welding-rod coatings.

Several titanium alloys suitable for making strong permanent magnets have been reported in the literature. One such alloy(83) contains iron, 5 to 9.5 percent aluminum, 1 to 3 percent titanium, and 20 to 30 percent nickel. Dehler(123) made permanent magnets containing 9 to 13.5 percent aluminum, 0 to 19 percent cobalt or 4 percent copper, 18 to 28 percent nickel or 4 percent titanium, and the remainder iron, with metal powders and a synthetic resin. These magnets are less brittle than cast magnets and can be made by mass production.

Beryllium-titanium-nickel alloys have been studied by Hessenbruch(152). These alloys combine high strength with resistance to mineral acids, alkalies, and organic materials. These alloys are used for springs, small tubes, etc. Claussen(98) has patented beryllium alloys suitable for rolled, vacuum-tight X-ray windows. These alloys, which are workable at about 500° C., are formed of beryllium in excess of 98 percent, a trace of oxygen, and the remainder titanium or zirconium chemically combined with at least part of the oxygen and serving to avoid embrittlement.

Titanium has been incorporated into alloys for use in gas turbines. One such alloy is a Westinghouse material, K-42-B, containing 42 percent nickel, 22 percent cobalt, 18 percent chromium, 2 percent titanium, and the balance iron(88). Its tensile properties at 1,110° F. are approximately 80 percent of those at room temperature; hourly creep rates at 1,000° F. and 50,000 pounds per square inch are of the order of 1.7 to 2.8 parts in 10,000,000; resistance to oxidation and corrosion is excellent; electrical resistivity varies from 112 microhms per cubic centimeter at room temperature to 124 microhms at 1,100° F.; and thermal expansivity is higher than that of ordinary steels and approximately the same as that of

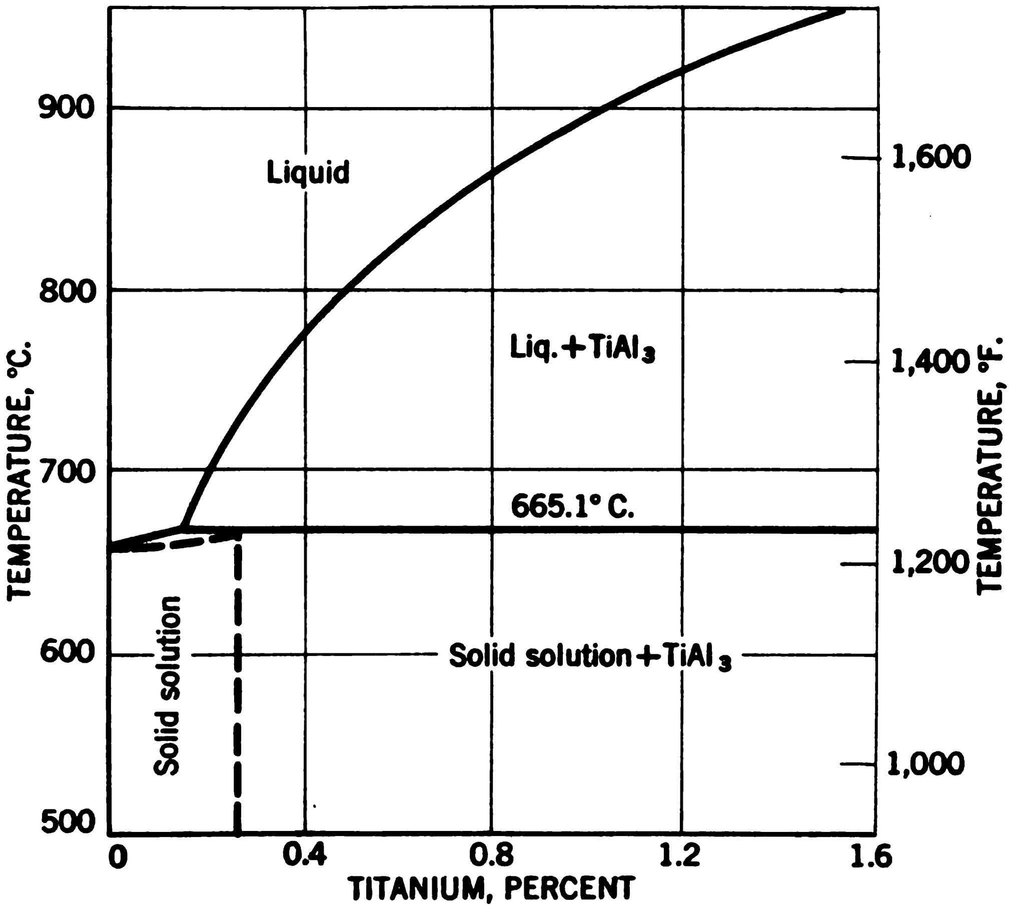

Figure 4. - Aluminum-titanium constitution diagram.

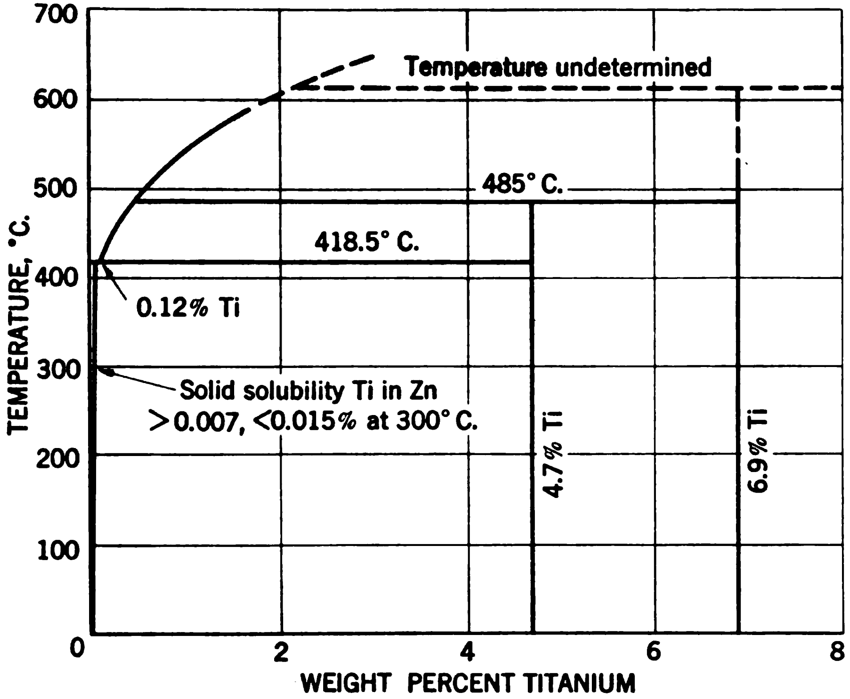

Figure 5. - Zinc-rich portion of zinc-titanium diagram.

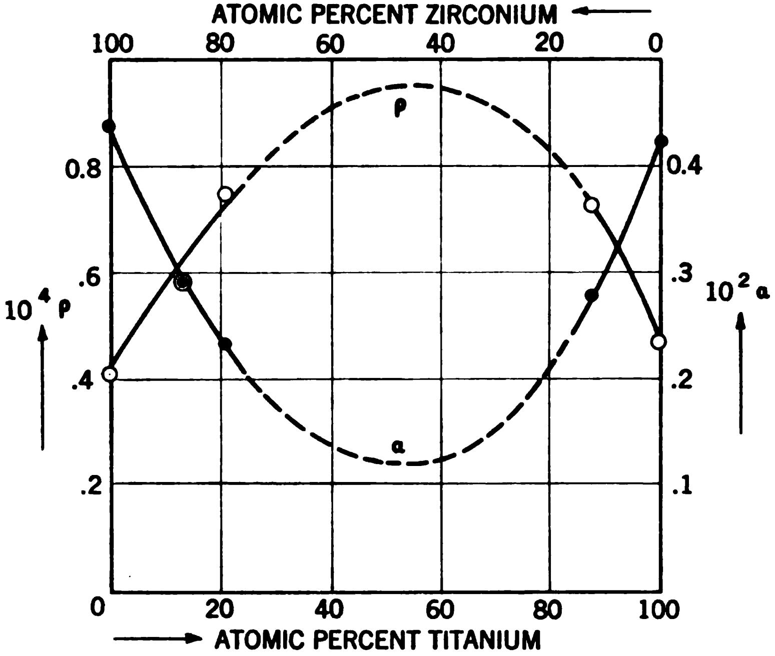

Figure 6. - Titanium-zirconium constitution diagram.

austenitic steels up to approximately 1,125° F. K-42-B is used in applications requiring high-temperature strength, plus resistance to oxidation and corrosion. The extremely low creep rate of K-42-B at temperatures up to 1,350° F. is a particular advantage for use as blades in gas turbines and superchargers. It is also used for bolts, springs, and furnace parts subject to high temperatures. A new variety of Inconel, containing 75 percent nickel, 14 percent chromium, 6 percent iron, 3 percent titanium, and 0.6 percent aluminum is now used for combustion chambers of jet-propulsion equipment. "Tinidur" is a high-temperature alloy, containing 30 percent nickel, 15 percent chromium, 1.8 percent titanium, 0.10 percent carbon, and the balance iron, which was said to have been used by Germany for turbine blades, jet-engine nozzles, and other extreme service. An alloy called Nimonic, containing 73 percent nickel, 23.5 percent chromium, 2.5 percent titanium, and the balance iron, was used by the British.

Titanium-Aluminum Alloys

The aluminum-titanium constitution diagram, as given by Fink and Van Horn(130), is shown in figure 4. It can be seen from this diagram that the liquidus intersects the peritectic horizontal at 665.1° C. and 0.18 percent titanium. The horizontal line at 661.5° C. represents the peritectic reaction $TiAl_3$+liquid=aluminum solid solution. Addition of titanium to aluminum gives a marked refinement of grain and consequent increase of strength by affording a greater number of nuclei at which crystallization begins. Ductility and soundness are also improved. It only takes about 0.1 to 0.2 percent of titanium to refine the grain enough for an increase of 15 or 20 percent in strength. This titanium content is easily obtained by an addition of about 2-1/2 pounds per hundred of a master alloy of aluminum containing 5 or 6 percent titanium. The presence of titanium in aluminum destined for use as an electric conductor is definitely undesirable since even very small amounts lower the conductivity.

Titanium-Zinc Alloys

The zinc-rich portion of the zinc-titanium diagram, as determined by Anderson and associates(71), is shown in figure 5. They found alloys having potentially useful properties in the rolled form in the zinc-titanium system. The best practice in the manufacture of these alloys is to prepare a zinc-titanium hardener by adding about 4 percent of titanium metal to molten zinc and holding under a boric acid cover, with frequent stirrings, at 750° C. until the titanium has dissolved. The desired titanium content can readily be obtained in the final alloy by adding the calculated amount of this hardener. A hot-rolled alloy containing 0.10 to 0.15 percent titanium with a nominal 0.12 percent titanium fabricated well but fell slightly short of the commercial zinc alloys in drawing properties. It was found that a final 50-percent cold-rolling would cause sufficiently better drawing properties to make the alloy of commercial interest. The decrease in creep resistance brought about by this cold-rolling could be overcome by subsequent annealing. This alloy appears free of work-hardening in the cold-rolled state. It seems quite feasible, then, to produce formed articles of good creep resistance from these zinc-titanium alloys by using cold-rolled strip to facilitate drawing and relying on a final heat treatment to obtain maximum creep resistance.

The system Zn-Ti was investigated thermally and microscopically on the zinc side by Gebhardt(136). Zn-Ti alloys were prepared directly from the pure metals. In this system a eutectic occurs, close to pure zinc, the eutectic temperature being 418° C. and the eutectic composition 0.15 percent titanium. With higher titanium contents the melting-point curve rises rapidly and reaches 1,000° C. at 5 percent titanium. Thermal analysis revealed two peritectic transformation temperatures. The solubility of titanium in solid zinc is extremely small at 400° C. Zinc dissolves less than 0.02 percent titanium.

Anderson and Edmunds(72) have patented alloys of good strength formed of zinc together with about 0.2 to 6 percent titanium, about 7.5 to 48.5 percent manganese, and about 0.02 to 5 percent aluminum, such alloys having an ability to retain a higher proportion of their impact strength during prolonged heating at moderately high temperatures than otherwise similar alloys containing no titanium.

Titanium-Zirconium Alloys

De Boer and Clausing(120) examined the system Zr-Ti over the whole concentration range. Both metals form solid solutions as shown in figure 6; the alloys can be worked, but they are less ductile than either component. The specific resistances are compiled in the following table where ρ_o is the resistivity of titanium at 0° C. and $\alpha = \frac{\rho_{100} - \rho_o}{100\rho_o}$:

Titanium, atomic percent	$10^4\rho_o$	100α
0	0.410	0.438
13.4	.585	.292
21.1	.75	.234
87.7	.73	.280
100	.475	.425

Miscellaneous Alloys

Titanium has been incorporated into alloys for high-speed cutting tools. A number of patents have been issued for this purpose, among which may be mentioned the following one by Schafer(208). Hard alloys of high tensile strength are formed of iron, together with zirconium 10 to 40 percent, columbium 3 to 20 percent, tantalum 1 to 8 percent, titanium 15 percent or less, and tungsten 25 percent or less.

The use of titanium in sintered hard alloys for machine tools is a relatively recent development. The carbide, nitride, and silicide may be used thus. All these compounds can be produced by the direct union of the respective elements at high temperatures. The relative proportion of the two constituent elements is a vital factor in obtaining the maximum hardness. Titanium carbide is more readily formed at a lower temperature if tungsten is also present. Titanium carbide is reported to be harder than tungsten carbide but not as good a conductor of heat. The use of titanium carbide in the tool is desirable only if maximum hardness is essential.

A Krupp patent(169) covers the production of a hard alloy by sintering or melting together a mixture of equal proportions of titanium carbide and nitride to produce working implements of every kind, particularly cutting tools. The toughness of this alloy can be improved by adding 7 to 10 percent of cobalt, when the sintering temperature is also lowered. Great hardness and strength are claimed. It has been reported that a sintered titanium-tungsten carbide material, corresponding to the formula $W_2Ti_2C_4$, was developed for use in tipping tools, which are said to show excellent resistance to shock and cratering, and for use in the manufacture of nozzles, valve seats, die inserts, etc. The Germans developed a supercutting, nontungsten alloy during the recent war, which consisted of vanadium carbide (45 percent) and titanium carbide (45 percent) bonded with metallic nickel (10 percent).

Miscellaneous

The products of partial reduction of the alkaline earth metal titanates have interesting and important electrical properties. If a mixture of TiO_2 and MgO is reduced in hydrogen the resulting mass possesses a very high temperature coefficient of electrical conductivity. Before the war a commercial product of this kind called URDOX was produced in Germany. According to Meyer(256) the reduction product of $CaO.TiO_2$ is practically a nonconductor at room temperature, while at 400° C. the conductivity increases to 150×10^{-5} reciprocal ohms.

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42. DE BOER, J. H., and FAST, J. D. Über die Darstellung der reinen Metalle der Titan Gruppe durch thermische Zersetzung ihrer Iodide. Ztschr. anorg. Chem., vol. 153, 1926, pp. 1-8. (Production of Ti by dissociation of the iodide.)

43. FAST, J. D. (Crack-Free Forming of Zirconium and Titanium.) Metallwirtschaft, vol. 17, 1938, pp. 459-462. (Pure Ti was prepared from the iodide and found to be ductile when cold.)

44. ______ (Preparation of Pure Metals of the Titanium Group by Thermal Decomposition of their Iodides. V. Titanium.) Ztschr. anorg. allgem. Chem., vol. 241, 1939, pp. 42-56. (Lower iodides in the dissociation process.)

45. KROLL, WILHELM. (Deformable Titanium and Zirconium.) Ztschr. anorg. Chem., vol. 234, 1937, pp. 42-50. (Reduction of TiO_2 with Ca and $CaCl_2$-$BaCl_2$ mixture under argon.)

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46. _____ (Titanium.) German Patent 674,625, Apr. 18, 1939. (Pure Ti is obtained by treating $TiCl_4$ with Ca at a high temperature.)

47. _____ Titanium. U. S. Patent. 2,205,854, June 25, 1940. ($TiCl_4$ is reduced with Ca or Mg at about 800° C. in the presence of an inert gas.)

48. _____ The Production of Ductile Titanium. Trans. Electrochem. Soc., vol. 78, 1940, pp. 35-47. ($TiCl_4$ is reduced with Mg at about 1,000° C. in the presence of pure argon.)

49. LELY, D., and HAMBURGER, L. Herstellung der Elemente Thorium, Uran, Zirkon und Titan. Ztschr. anorg. Chem., vol. 87, 1914, pp. 209-228. (Production of ductile Ti by reduction with Na in a bomb.)

50. VAN ARKEL, A. E. (Production of High-Melting Metals by Thermal Dissociation of their Compounds.) Metallwirtschaft, vol. 13, 1934, pp. 405-409, 511-514. (Production of ductile titanium by dissociation of the iodide.)

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Powder Metallurgy, Fabrication, Properties, and Uses of Ductile Titanium

52. ALEXANDER, PETER P. Packing Powdered Metals such as Titanium, Zirconium, Thorium, and Uranium to Prevent Oxidation. U. S. Patent 2,284,551, May 26, 1942. (Ti packed in a noble gas.)

53. BRIDGMAN, P. W. Compressibility and Pressure Coefficient of Resistance of Several Elements and Single Crystals. Proc. Am. Acad. Arts and Sci., vol. 64, 1929, pp. 51-73. (Linear compressibility of electrolytic Ti at 30° and at 75°.)

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55. DE HAAS, W. J., and VAN ALPHEN, P. M. (Change in Resistance of Graphite, Thorium, Titanium, and Titanium-Zirconium between 20.4° K. and 1.1° K.) Proc. Acad. Sci. Amsterdam, vol. 34, 1931, pp. 70-74. Resistance of Ti falls rapidly from 1.88° to 1.63° K., when it becomes superconducting.)

56. FAST, J. D., and JACOBS, F. M. (Extremely High Solubility of Nitrogen and Oxygen in Several Metals. Studies on Zirconium and Titanium.) Metallwirtschaft, vol. 17, 1938, pp. 641-644. (Ti has great nitrogen and oxygen solubility.)

57. FITZWILLIAM, J., KAUFMANN, A. R., and SQUIRE, C. F. Magnetic and X-ray Studies on Titanium and Zirconium with Dissolved Hydrogen. Jour. Chem. Phys., vol. 9, 1941, pp. 678-682. (Hydrogen, dissolved in Ti, changes the lattice of Ti from hexagonal close-packed to a nearly cubic face-centered lattice.)

58. GERTLER, SAMUEL E. Preparation and Working of Pure Chromium, Titanium, etc. U. S. Patent 2,206,395, July 2, 1940. (Process of treating Ti involves compressing the powdered metal to a coherent mass, then sintering to convert the mass into a soft, porous, and ductile state, and working to the desired shape.)

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59. GILLETT, H. W. Some Features of Ductile Zirconium and Titanium. Foote Prints, vol. 13, 1940, pp. 1-11. (Summary of certain physical properties; comparisons with Zr and Ta.)

60. HIDNERT, PETER. Thermal Expansion of Titanium. Nat. Bur. Standards Jour. Research, vol. 30, 1943, pp. 101-105 (Research Paper 1520). (Data are given on the linear thermal expansion of Ti (97.2 percent) at various temperatures between -190° and +700° C.)

61. JAEGER, F. M., ROSENBOHM, E., and FONTEYNE, R. (The Exact Measurement of the Specific Heats of Metals at High Temperatures. XXIII. The Calorimetric, Electric and Thermoelectric Behavior of Ductile Titanium.) Proc. Acad. Sci. Amsterdam, vol. 36, 1936, pp. 442-469. (Heat capacity of ductile Ti., electrical resistance of pure Ti is sensitive to traces of O_2; thermoelectric force of Ti against gold is variable and sensitive to traces of O_2.)

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63. KIEFFER, R., and HOTOP, W. (Comparison of the Properties of Sintered and Molten Metals and Alloys.) Kolloid Ztschr., vol. 104, 1943, pp. 208-223. (A review of the density, electrical, and mechanical properties of Ti.)

64. KROLL, W. (Several Qualities of Pure Titanium.) Metallwirtschaft, vol. 18, 1939, pp. 77-80. (Corrosion resistance of Ti is comparable to that of an 18-8 stainless steel.)

65. SQUIRE, C. F., and KAUFMANN, A. R. The Magnetic Susceptibility of Titanium and Zirconium. Jour. Chem. Phys., vol. 9, 1941, pp. 673-677. (The paramagnetic susceptibility of Ti increases linearly with temperature from 20° K. to a change in crystal structure that occurs at 1200° K.)

66. VAN LIEMPT, J. A. M. (The Production of Seamless Tubes from Materials of High Melting Points.) Metallwirtschaft, vol. 11, 1932, pp. 357-359. (Deposition of Ti electrochemically or by thermal decomposition on a core followed by solution of the core.)

Alloys of Titanium

67. ALEXANDER, PETER P. Coating Metal Surfaces such as those of Copper with Alloys containing Titanium. U. S. Patent 2,351,798, June 20, 1944. (Treatment involves coating with a thin layer of titanium hydride.)

68. _____ The Hydride Process. Metals and Alloys, vol. 8, 1937, pp. 263-264; vol. 9, 1938, pp. 45-48; Method for Production of Alloys. U. S. Patent 2,163,224, June 20, 1939. (Ti-Cu alloys are obtained using titanium hydride.)

69. _____ Powdered Alloys. U. S. Patent 2,287,771, June 30, 1942. (Ti alloys formed by the hydride process.)

70. ALLOYS LTD. (Alloys.) French Patent 835,468, Dec. 22, 1938. (Alloys of Ti with Cu, Ni, and Ag are obtained using titanium hydride.)

71. ANDERSON, E. A., BOYLE, E. J., and RAMSEY, P. W. Rolled Zinc-Titanium Alloys. Am. Inst. Min. and Met. Eng., Inst. Metals Div., Tech. Pub. 1687, 1944, 9 pp. (Equilibrium diagram of the Zn-Ti system.)

72. ANDERSON, EDMUND A., and EDMUNDS, GERALD. Alloys of Zinc, Titanium, Manganese, and Aluminum. U. S. Patent 2,303,105, Nov. 24, 1942. (Ti is beneficial in Zn-Mn-Al alloys.)

73. AREND, J., and LOBE, M. (Effect of Adding Small Quantities of Titanium to Structural Steels.) Stahl u. Eisen, vol. 53, 1933, pp. 604-606. Addition of up to 0.4 percent Ti to plain C steels containing 0.1 or 0.25 percent C improves yield point and tensile strength.)

74. ASTAKHOV, E. V. (Production of Ferrotitanium.) Ural. Met., No. 7, 1939, pp. 33-36; Chem. Abs., vol. 35, 1941, p. 4222. (Reduction of ilmenite concentrates by Al gives a 50 to 60 percent yield of ferrotitanium.)

75. AUSTIN, CHARLES K., and SAMANS, CARL H. The Metallography and Certain Physical Properties of Some Alloys of Cobalt, Iron, and Titanium. Trans. Am. Inst., Min. and Met. Eng., Inst. Metals Div., Tech. Pub. 1257, 1940, 11 pp. (The alloys investigated are susceptible to precipitation hardening; 600° C. is a favorable aging temperature.)

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77. BAIN, E. C., ABORN, R. H., and RUTHERFORD, J. J. B. The Nature and Prevention of Intergranular Corrosion in Austenitic Stainless Steels. Trans. Am. Soc. Steel Treat., vol. 21, 1933, pp. 481-509. (Addition of Ti stabilizes the alloy by the prevention of Cr-rich carbide formation.)

78. BANDEL, GERHARD. (Alloy for Exhaust Valves and Similar Parts on Airplanes.) Ger. Patent 731,128, Dec. 24, 1942. (Alloy contains C .05 to 1, Ni 40 to 90, Cr 5 to 30, Ti 1 to 5, Mn 0.1 to 3, Si 0.1 to 3 percent and Fe the rest.)

79. BASTIEN, PAUL. (Properties of Titanium and Boron Cast Irons.) Bull. assoc. tech. fonderie, vol. 13, 1939, pp. 276-292. (Depth of hardening and corrosion resistance decrease with increase in Ti content.)

80. BELOZERSKII, N. A. FREIDLINA, B. A., and REZVAYA, K. I. (Alloying Columbium, Tantalum, Hafnium, Zirconium, and Titanium with Iron, Chromium, Manganese, Nickel, Cobalt, and Copper.) Russian Patent 54, 976, May 31, 1939. (These alloys are prepared by electrolysis of the fused salts of Ti with a cathode of the metal that is to form the basis of the alloy.)

81. BENNEK, H., and SCHAFMEISTER, P. (Precipitation Hardening of Steels with 18 percent Chromium and 8 percent Nickel by addition of Beryllium, Boron, or Titanium and Its Influence on the Corrosion Resistance.) Arch. Eisenhuttenw., vol. 5, 1932, pp. 615-620. (influence of adding up to 3 percent Ti on the structural and mechanical properties of these steels.)

82. BERNSTORFF, HANS, and ALLENDÖRFER, ALBERT. Alloys. U. S. Patent 2,291,865, Aug. 4, 1942. (Alloys of Ti with Cu, Fe, Mo, and Ni by direct combination.)

83. BIEBER, CLARENCE G. Magnet Alloys. U. S. Patent 2,285,406, June 9, 1942. (Alloys contain Fe, Al, Ti, and Ni.)

84. ______ Alloy for Permanent Magnets. U. S. Patent 2,384,450, Sept. 11, 1945. (Al-Co-Fe-Ni-Ti alloy with 2 percent Ti for magnets.)

85. BIEBER, CLARENCE G., and BUCK, MORTIMER P. Age-Hardened Nickel Alloys. U. S. Patent 2,234,955, Mar. 18, 1941. (Process for age-hardening Ni alloys containing 0.25 to 1.0 percent Ti.)

86. BONSACK, W. Effects of Minor Alloying Elements on Aluminum Casting Alloy. Am. Soc. Test. Mat. Bull. 126, 1944, pp. 27-30. (Discussion of grain-refining effect of Ti.)

87. BOTH, EBERHARD. (The Creep Strength of a Special Alloy at 620°.) Ztschr. Metallkunde, vol. 36, 1944, pp. 149-152. (Creep strength at 620° C. of Cr-Co-Fe-Mo-Ni-W-Ti alloy with 13 percent Ti.)

88. BRACE, P. H. A New Alloy for Working at High Temperature. Metal Prog., vol. 41, 1942, pp. 354-360. (Mechanical properties of K-42-B, containing Ni 40 to 50, Co 20 to 30, Cr 15-30, Fe 5 to 15, and Ti 1 to 4 percent, are given.)

89. BURKHARDT, ARTHUR, KNABE, RICHARD, and RIEDERER, KARL. Magnesium Alloys. U. S. Patent 2,251,266, Aug. 5, 1941. (Ductile alloys contain Mg together with Bi 2 to 6, Cd 1 to 5, Al 1 to 5, Zn 1 to 7, and Ti about 0.2 to 4 percent.)

90. CANAC, LOUIS H. F., and SEGOL, EMILE, A. M. A. Alloys Suitable for Contact with Sea Water. U. S. Patent 2,310,214, Feb. 9, 1943. (Corrosion-resistant alloy: Mg 10 to 50, Zr. 0.01 to 3, Ti 0.08 to 1 percent and Al.)

91. CAPE, ARTHUR T., and FOERSTER, CHARLES V. Ferrous Alloys Suitable for Hard-facing and Casting Purposes. U. S. Patent 2,208,118, July 16, 1940. (Ferrous alloys are used containing about 1 percent Ti or less.)

92. CATHERALL, ALFRED C. Permanent Magnets. U. S. Patent 2,096, 670, Oct. 19, 1937. (Alloy contains Fe together with Ni 30 to 35, Al 10 to 15, and Ti about 0.4 to 4.0 percent.)

93. CHANDLER, HENRY T. Treatment of Molten Steel or Iron with "Reaction Alloys." U. S. Patent 2,370,289, Feb. 27, 1945. (Ti alloys for nitrogen deactivation in Fe or steel.)

94. CHERNIKOV, L. A. (Alloys of Titanium, Zirconium, Columbium, Tantalum and Other Rare Metals with Iron.) Russian Patent 59, 286, Feb. 28, 1941; Chem. Abs., vol. 39, 1945, p. 903. (Ti is added to the charge in the form of a concentrate together with reducing agents such as Fe-Si and Al.)

95. CHESTERFIELD, PERCY C. Cobalt-Chromium-Tungsten Alloys Suitable for High-Speed Cutting Tools. U. S. Patent 2,214,810, Sept. 17, 1940. (Tough, hard alloys are formed of Co 38 to 48, Cr 28 to 38, W about 15 to 16, C about 2.25 to 2.75, B about 0.18 to 0.20 and Ti about 2.5 to 3 percent.)

96. CHRISTEN, FRITZ. Magnesium Alloys. U. S. Patent 2,340,795, Feb. 1, 1944. (Alloys, suitable both for castings and rolling contain Mg-Al-Zn-Mn-Ti (0.5 to 1 percent.))

97. CLAUSSEN GERARD E. Structure Comprising Beryllium Windows for X-Ray Tubes. U. S. Patent 2,394,984, Feb. 19, 1946. (Be-Ti X-ray windows.)

98. _____ Beryllium Alloys Suitable for Rolled Vacuum Tight X-ray Windows. U. S. Patent 2,306,592, Dec. 29, 1942. (Alloys workable at 500° C. contain Be in excess of 98 percent, a trace of O_2, and the rest Ti chemically combined with some of the O_2.)

99. COMSTOCK, GEORGE F. Boron plus Titanium in Heat-Treated Steels. Metals and Alloys, vol. 17, 1943, pp. 978-983. (The ferroalloys Bortam and Carbortam are used for adding B+Ti to steels.)

100. _____ Titanium in Chromium - Manganese Stainless Steel. Iron Age, vol. 156, No. 6, 1945, pp. 62-66. (Ti increases yield strength.)

101. _____ Alloys for Use in Deoxidizing Iron and Steel. U. S. Patent 2,295,706, Sept. 15, 1942. (Alloys contain B 0.25 to 5, Ti 2 to 25, Al 5 to 25, Mn 5 to 30, Si 10 to 40 percent, and Fe the rest.)

102. _____ Alloys Containing Titanium, etc. U. S. Patents 2,146,330 and 2,146,331, Feb. 7, 1939. (Al alloys containing Ti require no quenching or heat-treatment to attain high strength.)

103. _____ Chromium - Titanium - Silicon Alloys Suitable for Use with Cast Iron. U. S. Patent 2,169,193, Aug. 8, 1939. (Alloys contain Ti 10 to 30, Cr 15 to 45, Si 20 to 45, Fe 0.1 to 25, Al 0.1 to 3 and C 0.01 to 1 percent.)

104. _____ Copper-Titanium-Silicon Alloys. U. S. Patent 2,086,604, July 13, 1937. (Heat-hardened alloys containing not over 1.5 percent Ti and less Si than Ti have an electrical conductivity over 35 percent, Rockwell hardness above 65 E and a yield point of at least 17,000 lb. per square in.)

105. _____ The Production and Industrial Uses of Titanium. Metals and Alloys, vol. 9, 1938, pp. 286-290, 314-318. (A correlated abstract.)

106. _____ Low-Carbon Ferrotitanium Silicon Alloys. U. S. Patent 2,064,150, Dec. 15, 1936. (Alloys for treating molten steel contains Fe, Ti (38 to 42), Si (7 to 15), Al (2 to 5) and C (0.01 to 0.12) percent.)

107. _____ Effect of Variations in Composition and Heat-Treatment on Some Properties of 4-6 Percent Chromium Steel Containing Molybdenum and Titanium. Trans. Am. Soc. Metals, Preprint 4, 1945, 30 pp. (Ti:C ratios of 3.5 : 5.5 give improved mechanical properties.)

108. _____ Titanium in Gray Cast Iron. Iron Age, vol. 131, No. 22, June 1933, pp. 857-859 and Adv. p. 12. (Fe treated with 2 percent of an alloy containing Ti-Si-Al-C is 23 percent stronger than untreated Fe.)

109. _____ The Constitution of Iron-Titanium Alloys. The Metals Handbook, Am. Soc. Metals, Cleveland, 1939, pp. 399-400. (Equilibrium diagram Fe-Ti.)

110. _____ A Study of Several Kinds of High-Strength Plate Steel. Metal Prog., vol. 46, 1944, pp. 1248-1253. (Ti can replace V in high-strength, weldable steel plates.)

111. _____ Some Interesting Properties of Titanium Steels. Jour. Am. Ceram. Soc., vol. 29, Jan. 1, 1946, pp. 1-7. (Titanium steel has some more desirable properties than regular enameling steel.)

112. _____ Copper-Titanium Alloys. U. S. Patent 2,189,198, Feb. 6, 1941. (A heat-hardened alloy suitable for welding - electrode tips contains Cu, Ti about 0.6 to 1.5 percent, Cr, and Si.)

113. _____ The Use of Titanium in Steelmaking. Blast Fur. and Steel Plant, vol. 21, 1933, pp. 412-414, 474-475. (Considers use of titanium as a deoxidizer and as an alloying element.).

114. COMSTOCK, G. F., and STARKWEATHER, E. R. Comparative Effect of Late Additions of Titanium and Silicon to Gray Cast Iron. Trans. Am. Foundrymen's Assoc., Preprint 38-15, 1938, 17 pp. (Increasing ferro-Ti additions gives increased strength and hardness.)

115. COMSTOCK, G. F., and WAINER, E. New Titanium Steel for Vitreous Enameling. Iron Age, vol. 155, No. 7, 1945, pp. 60-63, 152-153. (Steel containing about 0.04 percent C should contain about 0.20 percent Ti to prevent the formation of gas and blisters.)

116. DAHL, OTTO, and PFAFFENBERGER, JOACHIM. (Electromagnetic Apparatus.) German Patent 676,677, June 9, 1939. (Alloys containing Fe 60, Ni 40 and Ti 3.5 percent can be hardened by thermal treatment.)

117. _____ (Electromagnetic Apparatus.) German Patent 634,840, Sept. 21, 1936. (Alloys for making electromagnetic apparatus contain Ni 30 to 85 and Ti 1 to 10 percent, the remainder being Fe.)

118. DAVIS, JOHN R., STRAUSS, JEROME, and DUNN, HOLBERT E. Ferrotitanium Alloys. U. S. Patent 2,222,795, Nov. 26, 1940. (Method of making ferro-Ti alloys involves adding to a charge, containing Ti ore and a carbonaceous reducing agent, refractory material containing an oxide of Al or Mg and Mn or Si and melting the charge at about 2,000° C.)

119. DEAN, REGINALD S. Manganese Alloys. U. S. Patent 2,267,298, Dec. 23, 1941. (Mn-Ti alloys are made by dissolving TiO_2 in molten electrolytic Mn, adding metallic Al, and distilling to separate some of the electrolytic Mn from the Ti.)

120. DE BOER, J. H., and CLAUSING, P. (The Electrical Resistance of Titanium, Zirconium, and Their Solid Solutions.) Physica, vol. 10, 1930, pp. 267-269. (System Zr-Ti.)

121. DE GOLYER, ANTHONY G. Centrifugally Cast Alloys Suitable for Metal-Cutting Tools, etc. U. S. Patent 2,213,207, Sept. 3, 1940. (Centrifugally cast forms are produced from alloys containing W, Mo or U 5 to 30, B 0.25 to 5, Zr or Ti 0.25 to 7, Cr 1 to 25, Fe 5 to 40 percent and the balance Co.).

122. _____ Alloys Suitable for Metal Cutting Tools. U. S. Patents 2,147,63 and 2,147,637, Feb. 21, 1939. (Precipitation-hardened alloys are formed of Co (or Ni) together with B 0.5 to 4, Ti 0.25 to 7, and W, Mo, or U 2 to 30 percent.)

123. DEHLER, H. (Compacted Magnets with a Synthetic-Resin Binder.) Stahl u. Eisen, vol. 62, 1942, pp. 983-986. (Permanent magnets containing Al 9 to 13.5, Co 0 to 19 or Cu 4, Ni 18 to 28 or Ti 4 percent and Fe the rest are less brittle than cast magnets.)

124. DEUTSCHE EDELSTAHLWERKE A.-G. (Alloy for Permanent Magnets.) French Patent 829,598, June 30, 1938. (The alloy contains Co 1 to 35, Ti 3 to 20 percent and Fe the rest.)

125. ELECTRO METALLURGICAL CO. (Reduction of Ores Containing Rare Metals.) German Patent 678,505, July 21, 1939. (Ores containing Cb, Ta, and Ti are reduced by Si or Si alloys to give alloys predominating in Cb.)

126. ENDO, HIKOZO, and ITAGAKI, AKIRA. (An Investigation of Acid-Resisting Alloys. VII. Research for Nickel-Base Alloys Resistant to Hydrochloric Acid of Various Concentrations.) Nippon Kinzoku Gakkai Si, vol. 3, 1939, pp. 294-313. (Cast alloys containing 30 percent Mo and 10 percent W or 5 percent V and Fe or 5 percent Ti and Fe are resistant to acid.)

127. EFIMOFF, VIATCHESLAV V. Iron-Titanium-Chromium-Aluminum Alloys. U. S. Patent 2,266,745, Dec. 23, 1941. (Alloys for addition to steel contain Fe together with Ti 35 to 45, Cr 2 to 14, Si 1 to 14, Al 3 to 14 and less than 0.2 percent of C.)

128. ETCHELLS, HARRY. Alloys. British Patent 531,466, Jan. 6, 1941. (Alloy comprises Ni 25 to 50, Cr 15 to 30, Mo 2.5 to 5.0, Ti 0.10 to 1.50 percent, Fe the rest.)

129. FAST, J. D. (The Transition-Point Diagram of the Zirconium-Titanium System.) Rec. trav. chim, vol. 58, 1939, pp. 973-983. (Solid solutions of Zr and Ti have a transition-point minimum at 545° C.)

130. FINK, W. L., and VAN HORN, K. R. Constitution of Aluminum-Titanium Alloys. The Metals Handbook. Am. Soc. Metals, Cleveland, 1939, pp. 1233-1234. (Equilibrium diagram Al-Ti.)

131. FINK, WILLIAM L., VAN HORN, KENT R., and BUDGE, P. M. Constitution of High-Purity Aluminum-Titanium Alloys. Am. Inst. Min. and Met. Eng. Tech. Pub. 393, 1931, 18 pp. (Thermal, microscopic, and X-ray studies of high-purity aluminum-titanium alloys.)

132. FIRTH, THOS., and BROWN, JOHN, LTD. (Iron Alloys.) French Patent 834,883, Dec. 5, 1938. (Alloys having good mechanical properties at high temperatures contain Ni 20 to 40, Cr 6 to 20, Co 10 to 30, Ti 1 to 5, Cu up to 0.6 percent and Fe the rest.)

133. FISHEL, W. P., and ROBERTSON, BRISON. Distribution of Carbon between Titanium and Iron in Steels. Am. Inst. Mining Met. Eng., Tech. Pub. 1763, 1944, 4 pp. (In Fe-Ti-C steels, practically 100 percent of the Ti is present as Ti C if the wt. ratio of Ti: C in the alloy is less than 4.)

134. GAUTHIER, GASTON. Aluminum-Base Alloy with Protective Coating. U. S. Patent 2,376,681, May 22, 1945. (Coating Al-Cr-Cu-Mg-Ni-Zn alloys with corrosion-resistant Al-Mn-V-Zn-Zr-Ti alloys.)

135. _____ Improvement of Cast-Aluminum-Magnesium Alloys by Additions of Beryllium and Titanium. Foundry Trade Jour., vol. 59, 1938, pp. 373-374. (The alloys are used in machines for casting under pressure.)

136. GEBHARDT, ERICH. (The Systems Zinc-Titanium and Zinc-Zirconium.) Ztschr. Metallkunde, vol. 33, 1941, pp. 355-357. (Equilibrium diagram of the system Zn-Ti.)

137. GMELIN, L. Handbuch der anorganischen Chemie. 8th ed. Verlag Chemie, Berlin, 1937, System 35, Part A, No. 5, pp. 827-836. (Preparation, tensile strength, hardness, etc., of aluminum-titanium alloys.)

138. GOTTHARDWERKE A.-G. Fur elektrochemische Industrie. (Reduction material from Alumina - Containing Crude Material for Reducing Oxidic Metal Compounds.) Swiss Patent 214,553, Aug. 1, 1941; Chem. Abs., vol. 36, 1942, p. 4796. (An alloy used for final deoxidation of steel contains Al 45 to 60, Si 20 to 30, Ti 8 to 15 percent and Fe the rest.)

139. GROSSMAN, CORNELL J. Alloys for Casting Dentures, Etc., U. S. Patent 2,171,744, Sept. 5, 1939. (Co is used together with B 0.5 to 15, Ti 1 to 30, and Cr 3 to 45 percent.)

140. GRÜTZNER, A. Aluminum Legierungen. Suppl. 1, Part 1. Verlag Chemie, Berlin, 1939, pp. 368-469. (Al-Ti alloys. (Supplement to part A in Gmelin.))

141. GUILLET, L. (Copper alloys and Structural Quenching.) Cuivre et laiton, vol. 10, 1937, pp. 321-322. (Limit for solid solutions of Cu with Ti at 878° C. is 4.5 percent Ti; at ordinary temperature 0.4 percent Ti.)

142. HANSEN, M. Der Aufbau der Zweistofflegierungen. J. Springer, Berlin, 1936.

143. HENSEL, FRANZ R. Magnet Material. U. S. Patent 2,167,240, July 25, 1939. (For a strong permanent magnet, an alloy consisting basically of Ni, Ti, Co and Fe is made by the hydride process.)

144. HENSEL, F. R., and LARSEN, E. I. Age-Hardening Copper-Titanium Alloys. Trans. Am. Inst. Min. and Met. Eng., Inst. Metals Division, vol. 99, 1932, pp. 55-64. (Thermal and X-ray investigation, aging tests and physical properties.)

145. HERAEUS - VACUUMSCHMELZE A.-G. (Nickel Alloy for Surgical Needles and Similar Instruments.) German Patent 707,233, May 15, 1941. (Alloy contains up to 5 but preferably up to 3 percent Ti.)

146. _____ (Heat-Resistant Alloy.) German Patent 735,990, Apr. 22, 1943. (For parts having to withstand temperatures above 600° C. are used alloys of Cr-Fe-Mo (or W) - Mn-Si-Ti (0.3 to 20 percent) and Ni.)

147. _____ (Alloys for Springs.) French Patent 820,517, Nov. 13, 1937. (Alloys capable of being hardened by heating contain Be up to 2.5, Co 15 to 60, Fe 73 to 20, Ti or Si 0.5 to 10 percent and Ni the rest.)

148. _____ Magnetizable Metals. British Patent 463,901, Apr. 8, 1937. (A constant and stable permeability are obtained in weak magnetic fields for alloys containing Ni, Fe, and Ti.)

149. _____ (Highly Heat-Resistant Chromium-Nickel Alloys.) German Patent 730,630, Dec. 17, 1942. (Alloys of Ni-Cr-Fe-Mo (or W) -Mn-Si containing 0.3 to 20 percent Ti are used for parts exposed to 500-900° C. and higher.)

150. HERAEUS - VACUUMSCHMELZE A.-G., and ROHN, WILHELM. (Titanium Alloys.) German Patent 642,910, Mar. 19, 1937. (TiO_2 is reduced with H_2 in the presence of a metal of the Fe group or Cu.)

151. HESSENBRUCH, WERNER. (Beryllium-Copper Alloy.) German Patent 672,170, Feb. 2, 1939. (A hard Be-Cu alloy is obtained by substituting part of the required 3 percent Be by Ti.)

152. _____ (Beryllium and Beryllium alloys.) Metallwirtschaft, vol. 17, 1938, pp. 541-547. (Be-Ti-Ni alloys combine high strength with resistance to mineral acids, alkalies, and organic materials.)

153. _____ (Copper Alloy.) German Patent 671,973, Feb. 18, 1939. (An alloy for casting matrixes consists of Be 0.5 to 3.5, one or more metals as follows: Fe 0.2 to 5, Ni 0.2 to 20, or Co 0.2 to 10 percent and the rest Cu. Ti in amounts of 0.3 to 5 percent may be added.)

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154. HOWE, GOODWIN H. Alloys for Permanent Magnets. U. S. Patent 2,264,038, November 25, 1941. (Alloy contains Co 30 to 36, Ni 16 to 25, Ti 6 to 12, Al 5 to 7 percent, and Fe the rest.)

155. HUBER ÉS SIGMUND ACÉL-ÉS FÉMÁRGUYAR and BÉLA VÉCSEY. (Iron-Silicon - Titanium Alloy). Hungarian Patent 117,323, Dec. 1, 1937; Chem. Abs., vol. 32, 1938, p. 2897. (Slag from an Fe alloy, containing Ti 10 to 25 percent and Si 10 to 50 percent, contains much recoverable Ti.)

156. IRMANN, R. (Cast Alloy of Aluminum-Copper-Titanium.) Metallwirtschaft, vol. 20, 1941, pp. 809-814. (A cast alloy of Al-Cu-Ti containing 0.1 to 0.3 percent Ti and 4.5 percent Cu is used as a substitute for forged parts made of Al malleable alloys.)

157. JONAS, GOTTFRIED B. Permanent Magnets Suitable for Specified Heat-Treatment. U. S. Patent 2,245,477, June 10, 1941. (Magnets formed of Fe together with Ni about 16, Co about 25, Ti about 2.8 to 4.5 and Al 5.1 to 7 percent.)

158. JONES, WM. I. Metal Articles or Masses. British Patent 530,996, Dec. 27, 1940. (Al alloys sintered with titanium hydride.)

159. KAMURA, HEIHACHI. Method of Manufacturing Magnetic Iron and Steel. U. S. Patent 2,026,390, Dec. 31, 1935. (Comprises mixing together Fe of low C content, high-P reduced Fe, a small amount of Ti, and melting the mixture.)

160. KASE, TSUTOMU. (Metallic Cementation VIII. Cementation of Some Metals by means of Ferro-titanium Powder.) Kinzoku-no-Kenkyu, vol. 13, 1936, pp. 50-59; Chem. Abs., vol. 30, 1936, p. 3380. (Pulverized Fe-Ti alloy was used to study the penetration of Ti into Fe, Ni, and Cu at various temperatures between 800° and 1300° C.)

161. KIMPFLIN, GEORGES. (Aluminum Alloys.) Génie civil, vol. 118, 1941, pp. 238-241. (Composition, manufacture, physical behavior, and mechanical properties of Al alloys of low Ni and low Ti content.)

162. KROLL, WILHELM. (Titanium Alloys.) German Patent 718,822, Feb. 26, 1942. (An alloy of 10 to 60 percent of Ta, Cb, Mo, W, Zr, or V and the rest Ti is resistant to corrosion and has a high optical reflectance.)

163. _____ (Age-Hardening Copper-Titanium Alloys.) Ztschr. Metallkunde, vol. 23, 1931, pp. 33-34.

164. _____ Iron-Titanium Alloys. British Patent 352,964, Feb. 16, 1929. (Fe-Ti alloys (3 to 6 percent Ti) are hardened and then aged by annealing.)

165. _____ (Useful Titanium Alloys.) Metallwirtschaft, vol. 9, 1930, pp. 1043-1045. (Fe-Ti alloys can be rolled and used as alloy steels.)

166. _____ (Deformable Alloys of Titanium.) Ztschr. Metallkunde, vol. 29, 1937, pp. 189-192. (The most ductile alloys were made with Ni, Fe, Co, Mo, W, and Ta; influence of impurities on the hot malleability of Ti.)

167. KRUPP, FRIED., A.-G. (Alloy for Cutting and Hot-Working Tools.) German Patent 734,392, Mar. 18, 1943. (Alloy contains C-W (or Mo) -Co-Cr-Fe and Ti.)

168. _____ (Alloy for the Working Parts of Cutting Tools.) German Patent 733,126, Feb. 18, 1943. (An alloy of C 1.5 to 3, Co 35 to 55, W 12 to 25, Cr 20 to 35, Ti 0.5 to 6 percent and the rest Fe is used for cutting tool edges.)

169. _____ Tool Alloys. British Patent 365,895, June 16, 1930. (A hard tool alloy consists of a mixture of Ti carbide and Ti nitride sintered together.)

170. _____ Permanent-Magnet Alloys. British Patent 524,420, Aug. 6, 1940. (Fe-Co-Ni-Ti magnet alloys with Al or Zr present.)

172. _____ (Alloys for Permanent Magnets.) French Patent 849,214, Nov. 16, 1939. (Alloys contain Ni 5 to 40, Ti 0.5 to 20, Co 0.5 to 40, Al 0.5 to 10 percent and the rest Fe.)

173. KUSAKIN, P. S. (Obtaining Cuprotitanium and the Effect of Adding It to Alloys of Nonferrous Metals.) Ural,skii Gosudarst. Nauch-Issledovatel. Inst. Tavetnym Metal. Sbornik Nauch.-Issledovatel. Rabot, no. 1, 1935, pp. 95-109; Chem. Abs., vol. 31, 1937, p. 3854 (Reduction of TiO_2 with Al on a Cu bath at 1500° C.)

174. KUZNETSOV, A. A. (The Effects of the Coercive Force and the Residual Induction of the Material on the Magnetic Moment of a Linear Magnet.) Vestnik Elektroprom., no. 3, 1938, pp. 47-51. (The demagnetization curves are given for an Fe-Co-Ni-Ti-Al-alloy containing Co 27.2, Ni 17.7, Ti 6.7, and Al 3.7 percent.)

175. LAMORT, J. (Titanium-Iron Alloys.) Ferrum, vol. 8, 1914, p. 29. (Equilibrium diagram Fe-Ti.)

176. LAVES, F., and WALLBAUM, H. J. (The Crystal Chemistry of Titanium Alloys.) Naturwissenschaften, vol. 27, 1939, pp. 674-675.

177. LOBANOV, I. E. (The Effect of the Addition of Carbotitanium on the Properties of Cast Iron.) Liteinoe Delo, No. 10-11, 1939, pp. 28-31; Chem. Abs., vol. 36, 1942, p. 3764. (Addition of carbotitanium to cast iron produces finer graphite precipitates and a differentiation of pearlite.)

178. LOWRY, ERWIN F. Cobalt and Nickel Alloys Suitable for Use at High Temperatures. U. S. Patent 2,121,759, June 21, 1938. (A Co-Ni-base alloy is formed containing Co and Ni together 80 to 95, the Co being 45 to 85, Fe 20 to 5, and Ti 1 to 10 percent.)

179. MCLOTT, WM. C. Chromium-containing Alloys Suitable for Coating, Bondir or Edging Various Steel Articles. U. S. Patent 2,321,227, June 8, 1943. (Alloys are formed of Fe-Cr-Mo-Cu-Mn-Ti (0.3 to 1.5 percent - C-Si.)

180. MALKOV, L. P., and VASIL'EVA, V. V. (Oxidizability of Solid Alloys on Heating.) Legkie Metal, vol. 6, No. 5-6, 1937, pp. 42-45; Chem. Abs., vol. 33, 1939, p. 3734. (Ti-Cr-W alloys are most stable when hot; increasing the TiC content of an alloy increases its strength.)

181. MALLORY, P. R. and CO., INC. Copper-Base Alloys. British Patent 512,143, Aug. 30, 1939. (Hard alloys are made by quenching a cast material containing Ni 0.6 to 7, Si 0.2 to 5, Cd 0.1 to 10 percent and Cu the rest. The material may contain Ti up to 5 percent.)

182. MASUMOTO, HAKARI, and YAMAMOTO, TATUZI. (Magnetic Alloy.) Japanese Patent 133,864, Dec. 14, 1939. (To an alloy consisting of 6 to 12 percent Si, 3 to 10 percent Al, 81 to 90 percent Fe is added Sn 0.1 to 10.0, Ti 2 to 10, Pb 0.1 to 2.0, and Po 0.1 to 2.0 percent.)

183. MEERSON, G. A. The Formation of Solid Solutions in the System Titanium-Oxygen-Carbon and Conditions for Obtaining Titanium Carbide for the Production of Hard Alloys. Ann. sect. anal. phys.-chim., Inst. chim. gén. (U.S.S.R.), vol. 16, No. 1, 1943, pp. 197-219; Chem. Abs., vol. 39, 1945, p. 4310. (TiC for hard alloys by heating TiO_2 with C.)

184. MOND NICKEL CO., LTD. Nickel-Iron-Chromium Alloys. Brit. Patent 543,653, Mar. 6, 1942. (An age-hardenable alloy contains Ni-Ti-Cr-C-Fe, with 1 to 4 percent Ti.)

185. MOND NICKEL CO., LTD. Permanent Magnets. British Patent 541,474, Nov. 27, 1941. (Obtained by hot-forging a cast alloy containing Al 5 to 9, Ti 1 to 3, Ni 20 to 30 percent and Fe the rest.)

186. MOND NICKEL CO., LTD. Nickel-Iron Alloys. British Patent 540,357, Oct. 14, 1941. (Alloys having a low coefficient of thermal expansion consist of Ni 34.4 to 60, Ti 1 to 5, C 0 to 0.2 percent and Fe the rest.)

187. MORRAL, F. R., and BRAY, J. L. The Anodic Solution of Alloys. Trans. Electrochem. Soc., vol. 75, 1939, 14 pp. (preprint.) (Fe alloys containing 25 percent Ti have 1/10 the rate of corrosion of Fe.)

188. NAGURO, KAZUTAKA, and OTHERS. (Hard Alloys.) Japanese Patent 130,835, June 29, 1939. (An Fe alloy suitable for cutting tools contains 0.3 to 3.0 percent Ti.)

189. NEKRYTYI, S. S. (Carbotitan.) Liteinoe Delo, vol. 8, No. 10, 1937, pp. 43-46; Chem. Abs., vol. 34, 1940, p. 6207. (The desirable action of "Ferrocarbotitan" in the Fe melt depends upon its content of Ti and Al.)

190. NISHIMURA, HIDEO, and MATUMOTO, EITARO. (Effect of Titanium and Iron on Aluminum-Silicon Alloys.) (Suiyokwai-Shi, vol. 10, 1939, pp. 105-112. (When 0.5 percent Fe is present with Ti, the refining effect of metallic Na is overcome by the growth of the ternary compound $Al_3 Fe_2 Si_2$.)

191. NISHIMURA, HIDEO, and MATUMOTO, EITARO. (The Equilibrium Diagram of the Aluminum-Iron-Titanium System and the Segregation of Iron and Titanium.) Nippon Kinzoku Gakkai-Si, vol. 4, 1940, pp. 339-343. (In the Al-Ti system there is a peritectic point at 0.05 percent Ti and at 665° C.)

192. NORRIS, GEORGE L. Alloys for Addition to Iron and Steel. U. S. Patent 2,139,515, Dec. 6, 1938. (Alloys used as scavengers contain Si about 25 to 60, Ti about 5 to 25, Zr about 5 to 25, C not over 4 percent and Fe the rest.)

193. OTA, KIYOSI. (Cold-Pressing Rolls.) Japanese Patent 132,201, Sept. 19, 1939.) (An Fe alloy having a shore hardness of 110° contains 0.10 to 5.00 percent Ti.)

194. PARKER, E. R. The Development of Alloys for Use at Temperatures above 1000° F. Trans. Am. Soc. Metals, vol. 28, 1940, pp. 797-807. (High-temperature strength in the Fe-base alloys containing Mo, Cb, and Ti requires the presence of a critically dispersed stable compound.)

195. PHILIPS, N. V. **GLOEILAMPENFABRIEKEN.** Alloys for Permanent Magnets. British Patent 501,672, Mar. 3, 1939. (Alloy contains Ni 22.1 to 32, Co 1.5 to 15, Ti 0.5 to 7, Al 5 to 12, with or without Cu 0.5 to 8 percent, and the remainder Fe.)

196. _____ (Permanent Magnets.) French Patent 845,381, Aug., 21, 1939. (Ferromagnetic alloys of Ni, Co, Al, and Fe with Cu and (or) at most 8 percent Ti are used for permanent magnets.)

197. _____ Alloys for Permanent Magnets. British Patent 471,051, Aug. 20, 1937. (Magnets are made of alloy steel containing Ni 10 to 30, Co 4.5 to 30, and Ti 8.1 to 15 percent.)

198. _____ (Alloys for Permanent Magnets.) Fr. Patent 802,528, Sept. 7, 1936. (Alloys contain Ni 16, Co 28, Fe-Ti 46 percent, and Fe the rest.)

199. _____ (Alloys for Permanent Magnets.) Fr. Patent 802,956, Sept. 19, 1936. (Alloys contain Ni 15 to 25, Al 7 to 15, Ti 0.5 to 5 percent, and Fe the rest.)

200. PILLING, NORMAN B., and MERICA, PAUL D. Copper-Nickel-Titanium Alloys. U. S. Patent 2,102,238, Dec. 14, 1937. (Alloys of good strength and hardness contain Cu, Ni 2 to 50, and Ti 1 to 10 percent.)

201. PILLING, N. B., and TALBOT, A. M. Dispersion-hardening Alloys of Nickel and Iron-Nickel-Titanium. Am. Soc. Metals, Symposium on Age Hardening of Metals, 1939, pp. 231-257. (The hardening characteristics of Ti in Fe-Ni alloys are developed with particular application to the elastic strengthening of Invar and Elinvar.)

202. POLZGUTER, FRANZ. Permanent Magnets. U. S. Patent 2,227,946, Jan. 7, 1941. (Alloy contains Fe together with Co 30 to 36, Ni 16 to 20, Ti 6 to 8, and Al 4 to 6 percent.)

203. RABINOVICH, F. M. (Aluminum-Titanium Alloy.) (Russian Patent 43,737, July 31, 1935. (TiO_2 is introduced into the electrolyzer where Al electrolysis is carried out directly before the pouring of the metal.)

204. ROHLAND, WALTER. (Permanent Magnet.) German Patent 699,295, Oct. 31, 1940. (An alloy for making permanent magnets has the composition C 0 to 0.4, Ni 9 to 38, Ti 1 to 14, Cb and (or) Ta 0.5 to 11, Si 0 to 1.8 percent, and Fe the remainder.).

205. ROHN, WILHELM. Iron Alloys. U. S. Patent 2,071,942, Feb. 23, 1937. (Description of method of forming low-C Fe alloys containing Ti.)

206. ROHN, WILHELM, BOLLEWRATH, FRANZ, and CORNELIUS, HEINRICH. Valves for Internal-Combustion Engines. U. S. Patent 2,246,078, June 17, 1941. (Co-Ni-Fe-Cr-Mo (or W) alloy plus Ti for exhaust valves in combustion engines.)

207. ROLLA, LUIGI, and JANDELLI, ALDO. (Rare Earth Metals and their Alloys. Alloys of Lanthanum and Manganese.). Ber., vol. 75B, 1942, pp. 2091-2095. (Orienting experiments with La-Ti alloys presented difficulties because of the vaporization of La as the temperature approached the melting point of Ti.)

208. SCHAFER, CHARLES J. Alloys for High-Speed Cutting Tools and the Like. U. S. Patents 2,301,082, Nov. 3, 1942 and 2,307,960, Jan. 12, 1943. (Alloys of Fe-Zr-Cb-Ta-Ti and Fe-Zr-Cb-Ta-Ti-W, with 15 percent Ti or less, used for cutting tools.)

209. SCHMELLER, EDWARD A. Aluminum Alloys. U. S. Patents 2,189,834 and 2,189,835, Feb. 13, 1940. (Al alloys of good strength and workability contain Ti or ferro-Ti, together with Cu, Sn, Zn, Mg and Cr.)

210. SCHULZE, A. (Materials for Resistance Manometers.) Arch. tech. Messen, 1942, pp. J 136-139; Chem. Abs., vol. 39, 1945, p. 4825. (Au-Ti alloys for resistance manometers.)

211. SCHUMACHER, E. E., and ELLIS, W. C. Age Hardening of Copper-Titanium Alloys. Metals and Alloys, vol. 2, September 1931, p. 111. (Effect of heat-treatment on the hardness and electrical resistivity of Cu-Ti alloys.)

212. SCHWARZ, MAXIMILIAN V. (Determination of the Cavitation Resistance of Beryllium-Containing Alloys by the Water-Drop Method.) Ztschr. Metallkunde, vol. 35, 1943, pp. 76-78. (Resistance of alloy containing Ni 97, Be 2, and Ti 1 percent is exceptional.)

213. SELJESAETER, KAARE S. Ferrous Alloys for Magnets. U. S. Patent 2,087,336, July 20, 1937. (A permanently magnetic alloy contains Fe with about 3 to 9 percent Ti.)

214. SELJESATER, K. S., and ROGERS, B. A. Iron-Titanium Alloys. Trans. Am. Soc. Steel Treating, vol. 19, 1932, pp. 561-564.

215. SIEMENS AND HALSKE A.-G. Magnetic Alloys. British Patent 462,248, March 1937. (A permanent magnet is formed from a C-free Fe alloy containing Ni 20 to 40, Al 10 to 15, and Ti 0.7 to 5 percent.)

216. _____ (Magnetic Alloys.) French Patent 813,034, May 25, 1937. (Alloys for permanent magnets contain Co 30 to 36, Ni 16 to 20, Ti 6 to 10 percent, Fe, and Al.)

217. _____. Magnetic Alloys. British Patent 476,702, Dec. 14, 1937. (Permanent magnets are made from Fe alloys containing Co 30 to 36, Ni 16 to 25, Ti 6 to 12 percent, and Al.)

218. SOCIETÀ ANON. PROCESSI PRIVATIVE INDUSTRIALI. (Improving Iron-Beryllium Alloys.) British Patent 514,593, Nov. 13, 1939. (Into Fe-Be alloys containing 1 to 3 percent of Be is introduced Mo up to 1.5, Mn up to 3, W up to 3, Ti up to 1, or Cr up to 5 percent.)

219. SOCIETÀ ANON. PROCESSI PRIVATIVE INDUSTRIALI. (Beryllium Alloys.) Australian Patent 107,549, May 25, 1939. Ti induces the diffusion and homogenization of Be in Be alloys and crystalizes in a similar system to the Be.)

220. STAHLWERKE. RÖCHLING BUDERUS A.-G. (Alloy.) German Patent 652,061, Oct. 25, 1937. (An alloy capable of hot or cold working consists of Ta 3 to 50, C 0.1 to 4, Cr (or Ti) less than 10 percent, and Ni.)

221. _____ (Alloys Resistant to Corrosion.) French Patent 810,576, Mar. 24, 1937. (Alloys contain C less than 0.5, Mn 0.4 to 0.6, Si 0.2 to 3, Cr 20 to 30, Mo 1.8 to 4, Ti 0.5 to 3.5 percent, and Fe the rest.)

222. STAHLWERKE RÖCHLING BUDERUS A.-G., and KROPP, ALFRED. Iron Alloys. British Patent 473,201, Oct. 7, 1937. (Forks, spoons, dishes, etc., are made from Fe alloys containing Mn 12 to 50, Cr 3 to 15, Cu 0.5 to 10, and Ti 0 to 5 percent.)

223. STALHAUE, BERTIL. (The Possibilities for the Production of Ferrotitanium from Titaniferous Iron Ores.) Tek. Tid., Uppl., vol. A61, 1931, pp. 609-610; Chem. Abs., vol. 27, 1933, p. 49. (Reduction of TiO_2 with Al is performed directly in the steel bath.)

224. STARKWEATHER, E. R. Titanium in Cast Iron. Trans. Am. Foundrymen's Assoc., vol. 45, 1937, pp. 816-830. (Ti increases the tensile strength of cast Fe, renders the Fe more machinable, acts as a deoxidizer, and exerts a graphitizing effect.)

225. STEINBERG, RALPH H., and STEINBERG, DAVE. Nitriding Ferro-Alloys. Part 2. Metals and Alloys, vol. 20, 1944, p. 630. (Ferrotitanium absorbs 1.19 percent nitrogen when treated for 1 hr. at 1,290° F.)

226. STEINBERG, S. S. and KUSAKIN, P. S. (Attempts to Obtain Ferrotitanium.) Inst. Econ. Mineral Met., Moscow, No. 43, 1929, pp. 5-44. (Determined the conditions of C reduction of ores rich in TiO_2 in the process of preparing ferrotitanium.)

227. STEVENS, ARTHUR H. Alloys for the Production of Alloy Steels. British Patents 561,407, May 18, 1944, and 561,592, May 25, 1944. (Al-Be-B-Th-Zr-Ti alloys for steel manufacture.)

228. STRAUMANN, REINHARD. (Alloy.) German Patent 649,811, Sept. 3, 1937. (An alloy for spiral watch springs, etc., consists of Ni 30 to 38, W, Mo or Cr 5 to 10, Be 0.5 to 2, Ti 0.5 to 2, Si and Mn 1 percent, and the rest Fe.)

229. STRAUSS, JEROME, and DUNN, HOLBERT E. Ferrotitanium Alloys Suitable for Addition to Iron or Steel. U. S. Patent 2,287,712, June 23, 1942. (Alloys contain C-Ti-Zr-Mn-Fe-Si-Al.)

230. _____ Ferrotitanium Alloys. U. S. Patent 2,222,805, Nov. 26, 1940. (Method involves melting a charge containing Ti ore, a refractory material containing a substantial amount of an oxide or Zr or Be, and a carbonaceous reducing agent.)

231. TALBOT, ALBERT M. Age-Hardenable, Low-Expansion, Nickel-Iron-Titanium Alloys. U. S. Patents 2,266,481 and 2,266,482, Dec. 16, 1941. (Alloys suitable for age-hardening contain Ni, C, Fe and 2 to 3.5 percent Ti.)

232. TAMA, MANUEL. Induction Furnace for Melting Aluminum. Mech. Eng., vol. 66, 1944, pp. 731-736. (Manufacture of Al-Ti alloys in the induction furnace.)

233. THUM, E. E. The Book of Stainless Steel. Am. Soc. Metals, 1935, pp. 243-244, 248-250, 264, 307-308, 385,401, 438. (Effect of Ti on 5- and on 14-percent Cr steel, on 16-18 percent Cr-Fe, and on 18-8 Cr-Ni steel.)

234. TITANIUM ALLOY MFG. CO. Deoxidizing Steel, Iron, and Their Alloys. British Patent 562,642, July 11, 1944. (Deoxidizing alloy for steel contains Ti-B-Al-Mn-Si-Fe.)

235. TITANIUM ALLOY MFG. CO. (Iron Alloys.) French Patent 802,096, Aug. 26, 1936. (Alloy contains Ti 15 to 25, C 1.5 to 5, Si not more than 3.5, and Al not more than 3 percent.)

236. TITANIUM ALLOY MFG. CO. Alloy for use in Degasifying and Purifying Molten Steel. British Patent 452,092, Aug. 17, 1936. (Alloy contains Fe, Ti 15 to 25, C 1.5 to 5 percent, Si up to 3.5, and Al up to 3 percent.)

237. TOFANTE, W., and BÜTTINGHAUS, A. (The Iron Corner of the System Iron-Titanium-Carbon.) Arch. Eisenhüttenw, vol. 12, 1938, pp. 33-37. (The Fe-Ti-C system was examined with up to 3 percent C and 6 percent Ti.)

238. TYLER, PAUL M. Titanium - Its Uses in Metallurgy. Metals and Alloys, vol. 6, 1935, pp. 93-96. (Survey of the uses of titanium in alloys and in steel.)

239. THE UNITED STEEL COMPANIES, LTD., and SWINDEN, THOMAS. Iron Alloys. British Patent 476,115, Dec. 2, 1937. (Fe alloys for electrical resistances contain Cr 6.1 to 30, Al 3 to 12, C 0.07 to 0.2, and Ti up to 5 percent.)

240. VANADIUM CORP. OF AMERICA. Titanium-Vanadium Irons. Vanadium Steels and Irons, 1937, pp. 175-176. (Effect of V and Ti on Brinell hardness of cast Fe.)

241. VANCORAM REVIEW. Low-Carbon Ferrotitanium. Vol. 4, No. 2, Spring 1945, pp. 10, 21. (Composition of Ti alloys used in treating iron and steel.)

242. VAN LIEMPT, J. A. M., and DE VRIEND, J. A. (The Light of Combustion of Some Metals and Alloys II.) (Rec. Trav. chim., vol. 58, 1939, pp. 423-432. (The light of combustion of pure Ti and of an alloy containing Al and 2.5 percent Ti were determined.)

243. VOGEL, RUDOLF. (Observation of an Enforced Directional Separation in Solid Solutions.) Ztschr. Metallkunde, vol. 33, 1941, pp. 376-377. (When a ternary Ni-Fe-Ti alloy, containing 69 percent Ni, 14 percent Ti, and 17 percent Fe, solidifies, there separates out first an Fe-Ni-Ti solid solution, followed by a eutectic crystallization of a solid solution and the spear-like compound Ni_3Ti.)

244. VOGEL, R., and SCHLÜTER, W. (The Iron Corner of the System Iron-Silicon-Titanium.) Arch. Eisenhüttenw., vol. 12, 1938, pp. 207-212. (The system was investigated thermally and micrographically up to 30 percent Si and 30 percent Ti.)

245. VOGEL, R., and WALLBAUM, H. J. (The System Iron-Nickel-Nickel Titanide-Iron Titanide.) Arch. Eisenhüttenw., vol. 12, 1938, pp. 299-304. (The diagram of state Fe_2 Ni-Ti was established up to the pseudobinary section Fe_2Ti-Ni_3 Ti with Ti contents up to 30 percent.)

246. WALLBAUM, H. J. (The Systems of Iron-Group Metals with Titanium, Zirconium, Columbium, Tantalum.) Arch. Eisenhüttenw., vol. 14, 1941, pp. 521-526. (Equilibrium diagrams of Fe-Ti, Co-Ti, and Ni-Ti.)

247. _____ (Results of the Röntgenographic Structure Investigations of Alloys with the Composition AB2 of the Iron Metals with Titanium, Zirconium, Columbium, and Tantalum.) Ztschr. Krist., vol. 103, 1941, pp. 391-402. (Structures of Mn_2Ti and Fe_2Ti.)

248. WASMUHT, ROLAND. (The Precipitation-Hardening of Iron by Titanium.) Arch. Eisenhüttenw., vol. 5, 1931, pp. 45-56. (Investigation of influence of Si, Ni, Mn, Cr, Al, and C on precipitation-hardening in Fe-Ti alloys.)

249. WESTINGHOUSE ELECTRIC & MANUFACTURING CO. Nickel-Cobalt Alloy. German Patent 620,897, Oct. 29, 1935. (Ni-Co-Fe-Ti alloy containing 2 percent Ti.)

250. WITTE, HELMUT and WALLBAUM, HANS-JOACHIM. (Thermal and X-ray Study of the System Iron-Titanium.) Ztschr. Metallkunde, vol. 30, 1938, pp. 100-102. (Thermal, microscopic, and X-ray studies established the phase $TiFe_2$, melting at 1,530° C.)

251. WOLDMAN, NORMAN E., and METZLER, ROGER. Engineering Alloys. Am. Soc. Metals, 1945, p. 151. (Composition, mechanical properties, and uses of Konel.)

252. WULFF, JOHN. Powder Metallurgy. Am. Soc. Metals, 1942, pp. 148-151. (The hydride process.)

253. ZANDER, WALTER. (Alloy for Machine Parts.) German Patent 729,740, Nov. 25, 1942. (An alloy containing Mg 2 to 6, Fe 1 to 3, Mn 0.5 to 2.5, Si 0.8 to 2.5, Cr 0.2 to 1, Ti 0.05 to 1 percent, and Al the rest is used for parts exposed to gliding friction.)

254. ZUMBUSCH, W. (New Developments in Permanent Magnets from Iron-Nickel-Aluminum Alloys with and without Copper, Cobalt, and Titanium and their Construction and Applications.) Elektrotech u. Maschinebau, vol. 60, 1942, pp. 533-534. (Magnets of the following types are discussed: Fe-Ni-Co-Ti and Fe-Ni-Co-Al-Cu (Ti).)

255. ______ (Permanent Magnets of Iron-Nickel-Cobalt-Aluminum-Copper-Titanium Alloys with Magnetic Preferential Direction.) Arch. Eisenhüttenw., vol. 16, 1942, pp. 101-112. (Ti up to 1 percent improves the coercive force but impairs the magnetic energy value.)

Miscellaneous

256. MEYER, W. Elektronenleitung in festen chemischen Verbindungen. Ztschr. Elektrochem., vol. 50, 1944, p. 277. (Temperature dependence of conductivity for the reduction product of $CaO.TiO_2$.)